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GEOPHYSICAL INVESTIGATION OF BURIAL SITE 3-A, DEFENSE DEPOT OGDEN, UTAH

by

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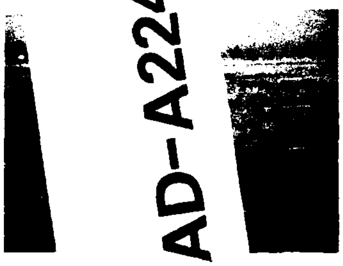

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Results of a comprehensive, integrated geophysical investigation of burial site 3-A at the Defense Depot Ogden, Utah (DDOU), are presented. DDOU has been active since 1941, with burial site 3 used for chemical agent disposal. Subsite 3-A was used for disposal of items which included US Military Chemical Surety Materials (CSM). Investigations of this subsite have been ongoing since 1981 including groundwater monitoring, limited geophysical investigations, excavation, and trenching. The geophysical investigations presented in this report were designed to detect anomalous conditions and clarify previous work performed at the site.

The geophysical program included ground penetrating radar, electromagnetic conductivity, and magnetics. The results of the investigation indicated six areas that were given high priority for further investigations due to the concurrence of anomalous conditions from all the tests performed. In addition to these six areas, there were several smaller areas that were given a lower priority for further analysis based on the detection of anomalous conditions from any one test performed.

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PREFACE

Field investigations were conducted by the US Army Engineer Waterways Experiment Station (WES) at the Defense Depot Ogen, Utah (DDOU), from 27 November - 2 December 1989. The Geotechnical Laboratory (GL) undertook this work for the US Army Engineer Division, Huntsville, Huntsville, Alabama. The scope of work involved investigation and assessment of possible buried hazards at burial site 3-A at DDOU (site 3-A is a part of operable unit 3). DDOU is a Federal-National priority list (NPL) site under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), due to past hazardous waste disposal activities. Burial site 3-A was used for disposal of items which included US Military Chemical Surety Materials. The investigation consisted of geophysical surveys performed by Messrs. Michael K. Sharp and Donald E. Yule of the Earthquake Engineering and Geosciences Division (EECD), GL, WES, and Messrs. Richard Lee and Ed Soltos, Technos, Inc., Florida.

This report was prepared by Mr. Michael K. Sharp and Mr. Donald E. Yule, EEGD. Technical support for the project was provided by Dr. Dwain Butler, EEGD. Appendix A contains a report by Mr. Richard Lee of Technos, Inc., summarizing the radar survey procedures and results. Site supervision for the work performed at DDOU was given by Mr. Del Fredde of the Environmental Office, DDOU-WA.

General supervision was provided by Mr. Joe Curro, Chief, Engineering Geophysics Branch (EGB), and Dr. A. G. Franklin, Chief, EEGD, GL. The project was under the overall supervision of Dr. W. F. Marcuson III, Chief, GL.

COL Larry B. Fulton, EN, was Commander and Director of WES during the investigation. Dr. Robert W. Whalin was Technical Director.

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LIST OF FIGURES

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
gamma	1.0	nano tesla
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres
square feet	0.09290304	square metres

GEOPHYSICAL INVESTIGATION OF BURIAL SITE 3-A
DEFENSE DEPOT OGDEN, UTAH

PART I: INTRODUCTION

Purpose

1. This study was conducted to assess the general, shallow subsurface conditions at burial site 3-A at the Defense Depot Ogden, Utah (DDOU), and to determine the presence or absence of contaminants in the material (Figure 1). The findings are intended to support and clarify previous work conducted at the site -- trenching, excavations, and geophysical tests performed to detect hazardous contaminants in the substratum. The results will also be used to determine whether subsequent remedial investigations, feasibility studies, and remedial actions can be appropriately implemented.

Background

2. DDOU has been active since 1941, and was reviewed in 1979 by the United States Army Toxic and Hazardous Materials Agency (USATHAMA). They reported the following about burial site 3:

> Burial site 3 was used during World War II and through the late 1940's. Chemical agents were buried here, including mustard and phosgene, in addition to HC cylinders and methyl bromide. Five to ten 5-gallon containers of mustard were buried in several separate pits. In addition, many chemical agent identification sets were disposed of in pits in this area. These sets contained glass vials of mustard, phosgene, other agents and simulant dilutions.

In 1981 the United States Army Environmental Hygiene Agency (USAEHA) installed two groundwater monitoring wells in the vicinity of burial site 3. Chemical agent contamination was not found in these two wells. In 1985 Environmental Science and Engineering, Inc., (ESE) performed limited geophysical investigations of the burial site 3-A area. These investigations confirmed the location of the burial site as indicated by aerial photography. In 1986

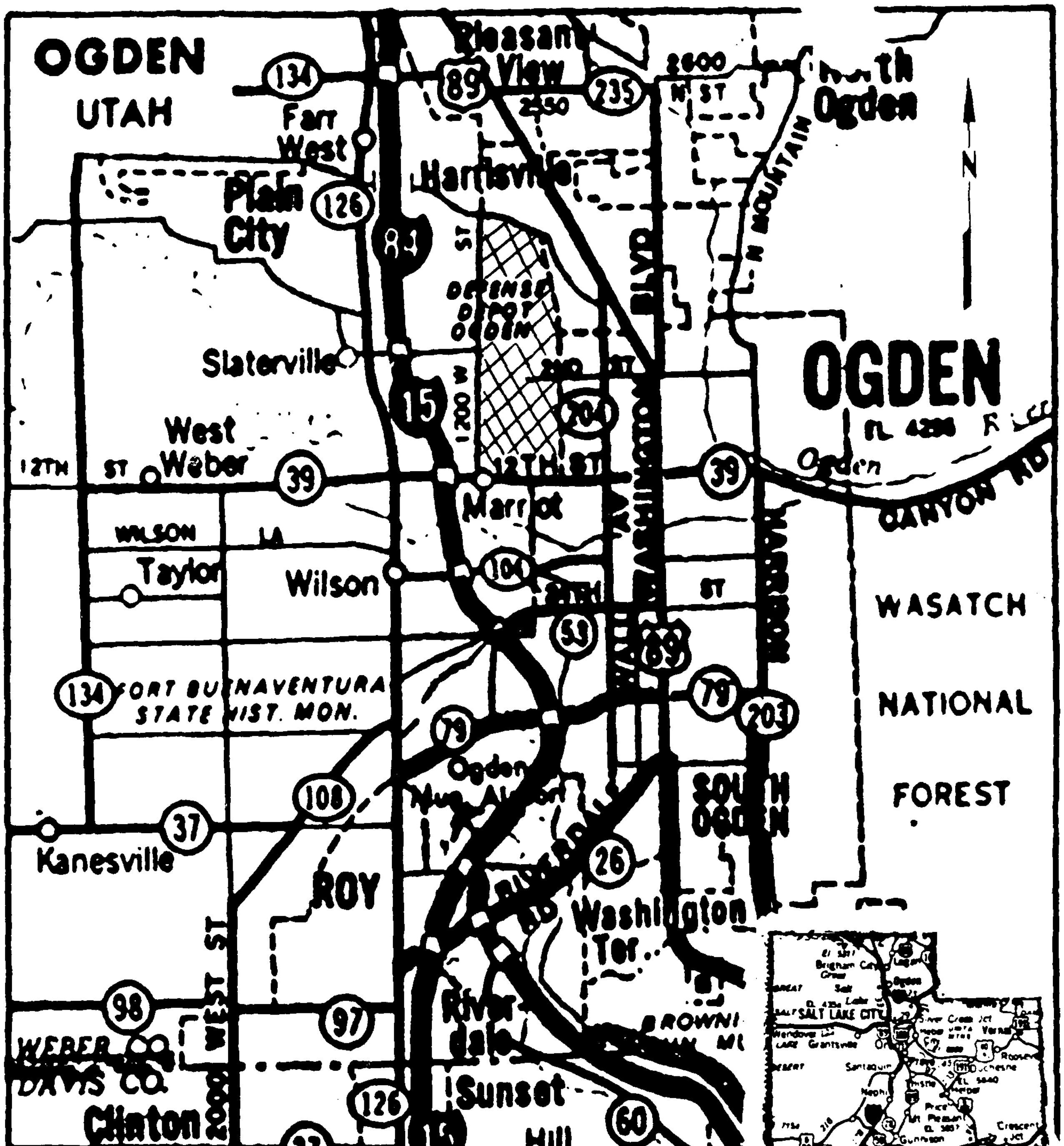

Figure 1. Defense Depot Ogden, Utah location map.

ESE installed four additional wells in the burial site 3-A area. No chemical agent contamination was found; however, the wells may not have been appropriately placed as evidenced by groundwater surface elevation contour maps and estimates of groundwater flow velocities. In 1988 James M. Montgomery Consulting Engineers, Inc. (JMM), installed three groundwater monitoring wells at nearby downgradient locations from burial site 3-A. These wells have been analyzed for chemical agent contamination and indicate that the mustard degradation product, thiodiglycol, is absent.

3. During the period 16 May to 2 June 1988, the Dugway Proving Ground Detachment of the US Army Technical Escort Service conducted excavations of burial site 3-A. The excavations were located in areas considered suspect, based upon previous work discussed above. Locations of pits and trenches, along with locations of materials encountered are shown in Figure 2. The Technical Escort Service personnel also performed limited metal detector sweeps of the trench sites during excavation procedures. During the excavations performed by military personnel in 1988, the following potentially hazardous materials were encountered:

- One empty industrial type compressed gas cylinder and four smaller metal tanks.
- One steel 55 gallon drum.
- Numerous US Military "M-18" chemical agent detector kits.
- Numerous small metal containers each containing three glass vials containing approximately 40 milliliters of Chloroacetophenone in chloroform.
- Components of defused smoke and riot gas grenades.
- Components of "M-1" chemical agent identification kits.
- Empty 2 and 55-gallon drums.

The M-18 detection kits were used to determine if chemical warfare agents were in use under battlefield conditions. The kits do not contain CSM (Chemical Surety Material), but may contain other materials which may be hazardous. Chloroacetophenone in chloroform is used to generate riot gas (CN). The M-1

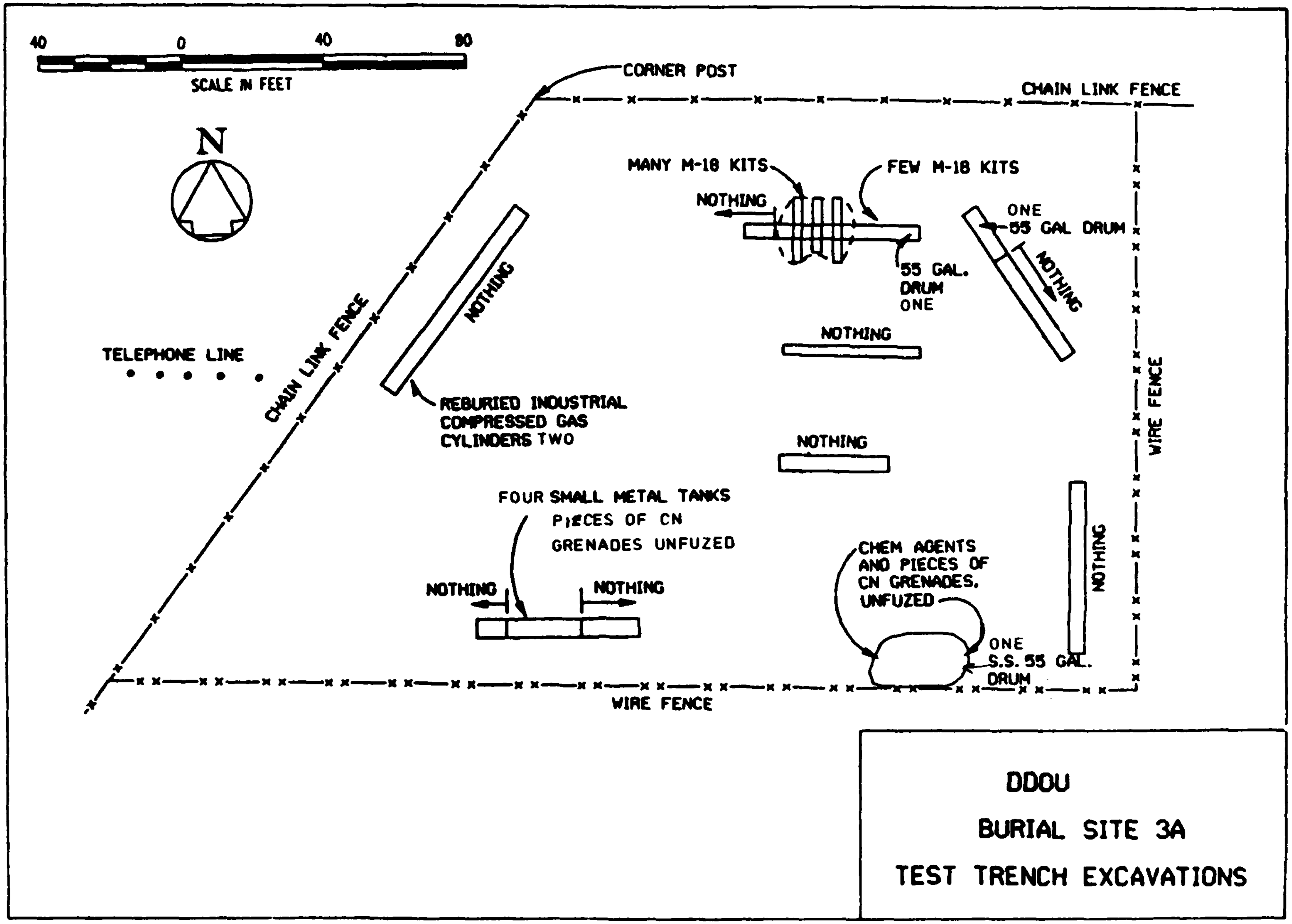

Figure 2. Burial site 3-A trenching and excavation activity (from DDOU).

kits contain actual dilute CSM including mustard as well as extremely small amounts of other agents impregnated in activated charcoal. All items encountered were reburied at the site, except for the CSM items which were turned over to the US Army. There were a total of 99 vials and bottles containing known or suspected CSM materials removed by Tech Escort. In addition, 9 charcoal filled jars of agent CN were removed. The Tech Escort personnel collected 22 soil samples from within the site, and analysis showed most of the samples were not contaminated; however, a few samples did contain elevated levels of chemical agents.

Scope

4. To aid in the assessment of burial site 3-A, a geophysical survey program was planned and performed at the site. The geophysical surveys were conducted to help delineate any anomalies indicative of buried waste, waste containers, and boundaries of burial trenches. Three different geophysical methods were utilized at the burial site -- ground penetrating radar (GPR), electromagnetic induction (EM), and magnetics. The surveys utilized a Geonics[1] EM-31 Terrain Conductivity System, a Geonics EM-38 Terrain Conductivity System, an EDA[2] OMNI IV Magnetometer System, and the GSSI[3] model 4800 GPR.

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[1]Geonics Limited, Mississauga, Ontario, Canada.
[2]EDA Instruments Inc., Toronto, Ontario, Canada.
[3]Geophysical Survey Systems Inc., Hudson, New Hampshire

PART II: SITE DESCRIPTION

General

5. The DDOU is located in a region known as the Ogden Valley, which is a fault trough bounded on the east and west by faults dipping toward the middle of the valley. The valley is composed of unconsolidated deposits of clay, sand, and gravel. These materials range to a depth of more than 600 ft[1] (183 m) and are believed to be pre-Bonneville alluvium. These materials are stream and lake deposits and in places are well sorted and stratified (Legette and Taylor 1937). The DDOU is located approximately 3.5 miles (5.6 km) west of the Wasatch mountain range and approximately 36 miles (58 km) north of Salt Lake City.

6. Burial site 3 is located in the southwestern portion of DDOU, and consists of three subsites; 3-A, 3-B and 3-C. Site 3-A, was used for the disposal of items which include US Military Chemical Surety Materials (CSM). This site was the target for all the investigations in Paragraph 2 and 3, as well as the geophysical investigation described herein. Burial site 3-A is located near the center of burial site 3, has a trapezoidal shape and encompasses approximately 70,625 ft^2 (6561 m^2). The entire area is enclosed by a 6 ft (1.8 m) chain link fence.

Subsurface Geology

7. Data concerning the subsurface geology conditions of the site were obtained from borings by JMM, completed on 17 November 1988. These borings were made to establish shallow monitoring wells in the area. The borings indicated silty material to a depth of 5 ft (1.5 m) where clean, coarse to very coarse grained sand was encountered. This material continued to a depth

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[1] A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 7.

11 ft (3.4 m) where the sand became mixed with silt and gravels up to 2 in. in diameter. The holes were not sampled again until a depth of 31 ft (9.5 m) was reached and clay was found. The borings reveal a water table at 7 ft (2.1 m). A water table contour map was compiled from information obtained by USAEHA (1987). This map revealed that the water table slopes to the northwest and that groundwater flow will be in that direction.

PART III: GEOPHYSICAL TEST PRINCIPLES AND FIELD PROCEDURES

Magnetic Method

8. The magnetic survey was performed utilizing a proton precession magnetometer (Telford et al, 1973). The proton precession magnetometer measures the absolute value of the total magnetic field intensity with an accuracy of 1 gamma (or 1 nano tesla, nT), in the earth's field of approximately 50,000 gammas. The total magnetic field intensity is a scalar measurement of the magnitude of the earth's field vector independent of its direction. The total field is a vector sum of the earth's main field and any local anomalous field component in the direction of the main earth's field.

9. Magnetic anomalies in the earth's magnetic field are caused by two different kinds of magnetism: induced and remanent (permanent) magnetization. Induced magnetization refers to the action of the field on subsurface material, wherein the ambient field is enhanced or diminished depending on the magnetic properties of the material. The resulting magnetization is directly proportional to the intensity of the ambient field and to the magnetic susceptibility. The remanent or permanent magnetization is often the predominant magnetization in many igneous rocks and iron alloys. Permanent magnetization depends upon the metallurgical properties and the thermal, mechanical, and magnetic history of the specimen. This type of magnetism is independent of the field in which it is measured (Breiner 1973).

10. A magnetic anomaly represents a local disturbance in the earth's magnetic field which arises from a localized change in magnetization, or magnetization contrast. The observed anomaly expresses the net effect of the induced and remanent magnetization and the earth's field which usually have different directions and intensities of magnetization. Depth of detection of a localized subsurface feature depends on mass, magnetization, shape and orientation, and state of deterioration of the feature.

EM Induction

11. The EM-31 and EM-38 are inductive electromagnetic devices used to measure the earth's apparent ground conductivity. The responses are directly proportional to conductivity and inversely proportional to resistivity. The basic operation utilizes a transmitter coil (Tx) energized with an alternating current at an audio frequency and a receiver coil (Rx) located a short distance away. The time varying magnetic field arising from the alternating current in the transmitter coil induces currents in the earth. These currents generate a secondary magnetic field which is sensed, together with the primary field, by the receiver coil. In general, this secondary magnetic field is a complicated function of the intercoil spacing, the operating frequency, and the ground conductivity. Under certain constraints, called the low induction condition, the secondary magnetic field is a very simple function of these variables. Under these constraints, the ratio of the secondary to the primary field is linearly proportional to the terrain conductivity. The apparent conductivity indicated by the EM-31 and EM-38 depends on measurement of the secondary to primary field ratio and assumes low induction conditions. The units of conductivity are the mho (Siemen) per metre or, more conveniently, the millimho per meter.

12. There are two components of the induced magnetic field measured by the EM-31. The first is the quadrature-phase component which gives the ground conductivity measurement. The second is the inphase component, which is used primarily for calibration purposes; however, the inphase component is significantly more sensitive to large metallic objects and hence very useful when looking for buried metal containers. Experiments have indicated that the EM-31 can detect a single 45 gal oil drum at a depth of about 12 ft (3.7m) using the inphase component of the meter.

13. The EM-31 has an intercoil spacing of 12 ft (3.7m) and has an effective depth of exploration of about 20 ft (6 m). The EM-31 meter reading is a weighted average of the earth's conductivity as a function of depth. The weighting of sensitivity with depth is illustrated in Figure 3 (Geonics 1981). A thorough investigation to a depth of 13 ft (4 m) is possible, but below that depth the effect of conductive anomalies becomes more difficult to distinguish as their depth increases. The instrument can be operated in both a horizontal

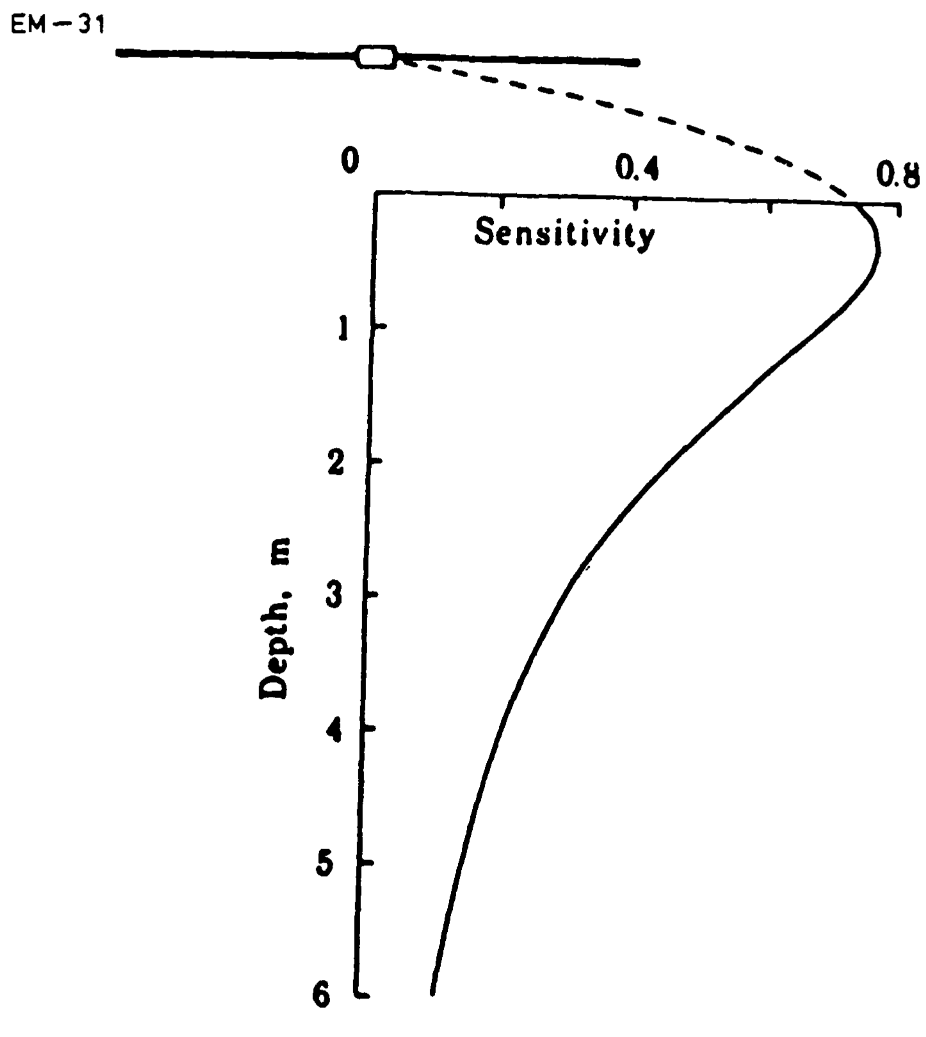

Figure 3. Sensitivity versus depth for the EM-31 Terrain Conductivity meter.

and vertical orientation which changes the effective depth of exploration. The instrument is normally carried such that the transmitter and receiver coils are oriented vertically, which gives the maximum penetration depth. It can be used in either a discrete or continuous-read mode.

14. The EM-38 operates under the same principles as described for the EM-31 above, measuring the apparent conductivity of the ground in millimho per meter. The instrument has an intercoil spacing of 3 ft (1 m), and a maximum depth of investigation of 6 ft (1.5 m). Both quadrature-phase and inphase readings can be taken to measure conductivity and change in metallic susceptibility, as with the EM-31. The EM-38 can also be operated in both the vertical and horizontal dipole mode coil configurations. In the vertical dipole mode, the relative sensitivity to near surface material is very low (being zero at the surface). The sensitivity increases with depth, becomes a maximum at about 1.3 ft (0.4 m), and decreases slowly thereafter. In the horizontal dipole mode of operation the relative sensitivity is greatest to material at the surface, and decreases thereafter with depth. The large difference in the response to near surface material in the two coil configurations allows a quick method for determining whether the near surface material is more or less conductive than is material at depth. Although the EM-38 has a much smaller depth of investigation than the EM-31, it has correspondingly greater horizontal resolution capability than the EM-31.

GPR Principles

15. The GPR method responds to changes in soil and rock conditions having sufficiently different electrical properties such as those caused by clay content, soil moisture or ground water, cementation, man-made objects, voids, etc. The data collection process involves moving an antenna across the ground surface and transmitting high frequency radio waves into the subsurface. The signal is reflected off subsurface interferences and back to the receiving antenna where the variations in the return signal are continuously recorded. Analysis and filtering of the recorded signal produces a cross-sectional profile of the subsurface conditions. The depth of

exploration using GPR is dependent on the properties of the soil and rock at the site and the antenna frequency. The best results are attained in dry, sandy, or gravelly subsurface material. For a more detailed discussion of GPR principles, see Appendix A.

Field Procedure

16. Initially, a grid was established to encompass the trapezoidal burial site 3-A, (Figure 4). The grid was rectangular in shape measuring 380 ft (115.8 m) in the "X-direction" and 460 ft (140.2 m) in the "Y-direction". The grid axis was established parallel to the eastern and northern portions of the chain link fence. The X-direction is 20 deg west of north. There are 480 stations in the grid located on 20 ft (6.1 m) centers. The (0,0) station was referenced from the southeast corner post of the fence, 70 ft (21.34 m) south and 60 ft (18.28 m) east of that point. This configuration gives 183 stations inside the fenced area and 293 stations outside the fenced area. The stations were located with PVC stakes, which do not interfere with the magnetic or radar surveys.

17. Since the area inside the fence (burial site 3-A) is of prime importance, the survey was divided into two testing configurations. The area inside the fence was surveyed at 10-ft (3.05 m) intervals; whereas, the area outside the fence was surveyed at 20-ft (6.1 m) intervals. Coverage outside the fence was desired to cover or "check for" the possibility of chemical agent burial outside the designated area.

18. Magnetic measurements were taken over the entire gridded area. The layout of all magnetic survey points for the entire area is shown in Figure 5. The data were stored in internal memory of the magnetometer and transferred to a portable field computer at the conclusion of each day. The survey was conducted in what is termed a looping procedure. In this procedure, one point is established as the base and remains as such throughout the survey. The base station is reoccupied at approximately 30 min intervals; in this manner, any drift in the earth's magnetic field can be identified and removed. Inside the fence, measurements were taken at 10-ft (3.05 m) intervals, for a total of 731 measurements. Outside the fence, readings were made at 20-ft (6.1 m) intervals to give another 293 points.

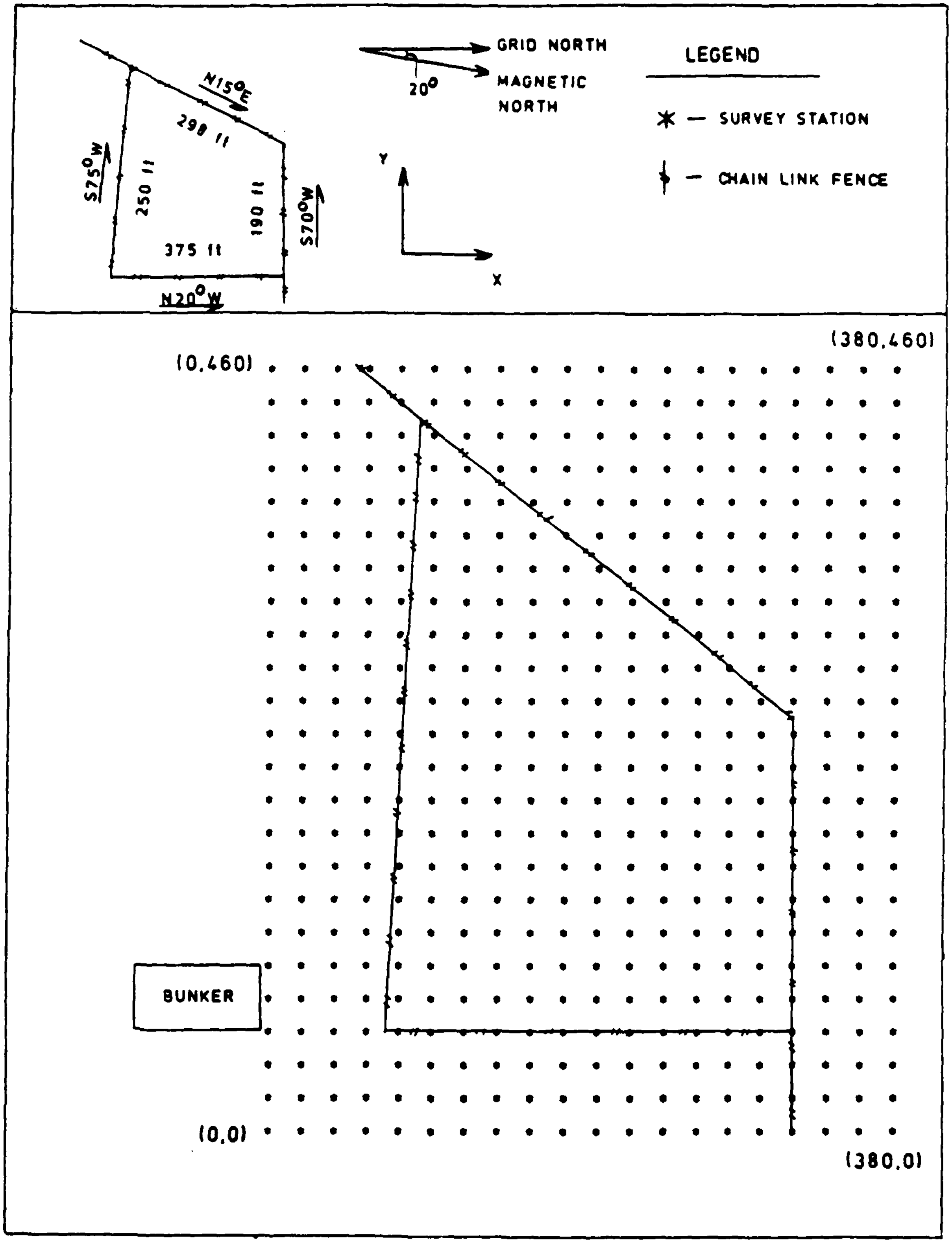

Figure 4. Grid layout for geophysical work conducted at the 3-A burial site.

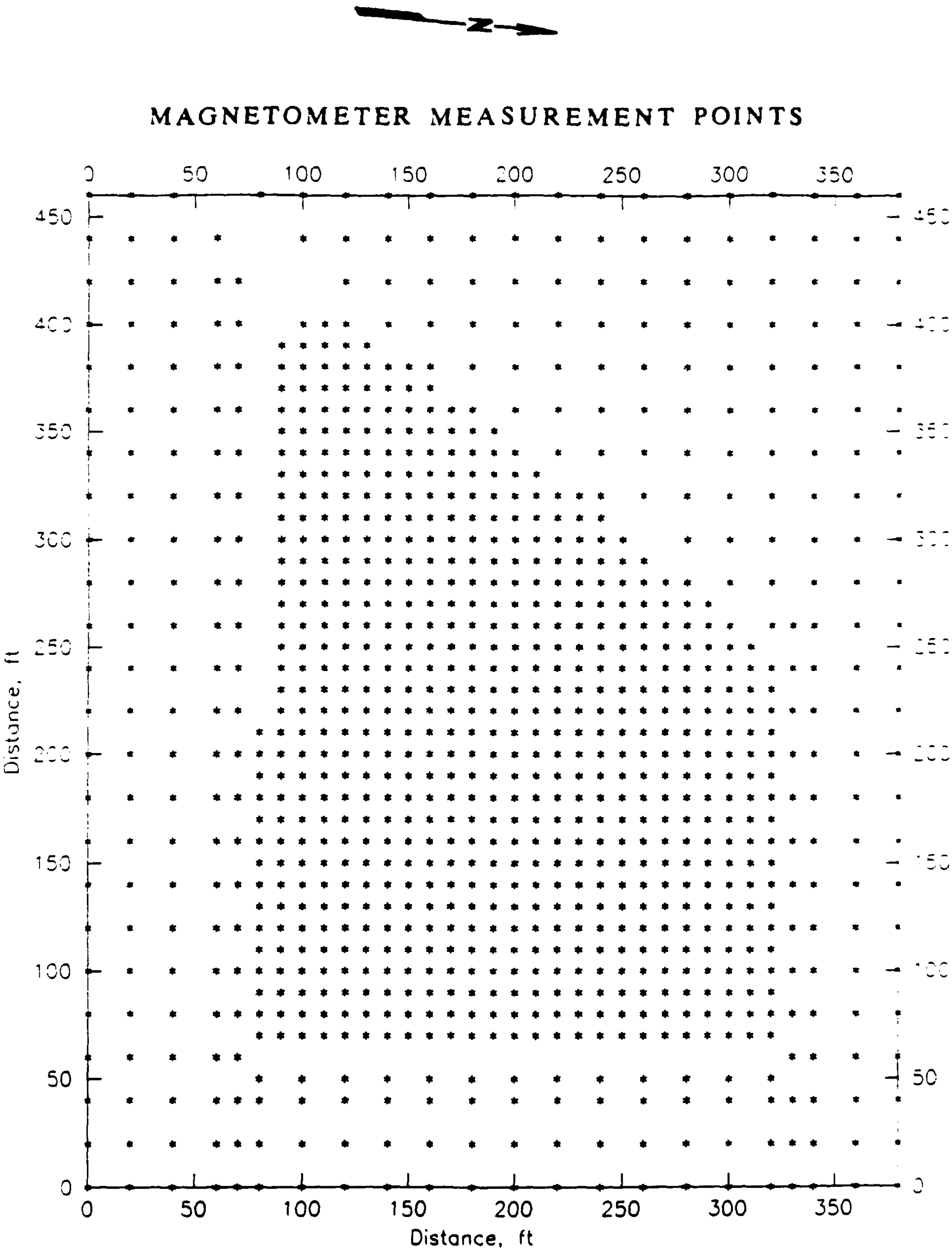

Figure 5. Survey stations for the magnetometer test.

19. The EM-31 system was used to take measurements in both the quadrature-phase (conductivity) and inphase (magnetic susceptibility) modes. The layout of all measurement points for the entire area is shown in Figure 6. Inside the fenced area, conductivity measurements were taken (with the transmitter and receiver poles oriented vertically to give maximum depth of penetration) point-by-point on 10-ft (3.05 m) centers. The survey covered the entire area inside the fence to within 10 ft (3.05 m) of the fence all the way around. With this type coverage, 731 individual measurement points were obtained inside the fenced area. Also, the area was "swept" with the instrument set at the inphase mode for maximum sensitivity to buried metallic objects. "Swept" refers to the procedure whereby the meter is set for continuous-read, and areas exhibiting anomalous readings are flagged. The anomalous areas are then covered more thoroughly to delineate boundaries. When the meter is set in the inphase mode and reading continuously, anomalies will appear as localized deflections of the meter in either the positive or negative direction. Outside the fence, only conductivity measurements were made point-by-point at 20-ft (6.1 m) intervals. There were a total of 293 measurements made outside the fenced area. The measurements were recorded on a digital data logger and transferred to a portable field computer at the conclusion of each day.

20. The EM-38 system was used to take measurements of both conductivity and in-phase response. Conductivity measurements were taken inside the fence covering the entire area to within 5-ft (1.5 m) of the fence. The readings were taken at 10-ft (3.05 m) intervals, as with the EM-31 described above. Both horizontal and vertical orientations of the instrument were recorded at each grid point, resulting in over 1,400 measurements. Measurements were also made outside the fence, to within 5-ft (1.5 m) of the fence. The EM-38 is capable of taking measurements much closer to metallic objects (such as the fence), without considerable influence from those objects, than are the EM-31 and magnetometer. As described earlier, the area inside the fence was swept with the instrument in the vertical dipole mode thereby taking inphase readings. Here again, areas that revealed anomalous responses were flagged.

21. The GPR survey covered the entire area of the grid inside and outside the fence. The area was first tested with different antennae to determine which one functioned most efficiently and gave the greatest

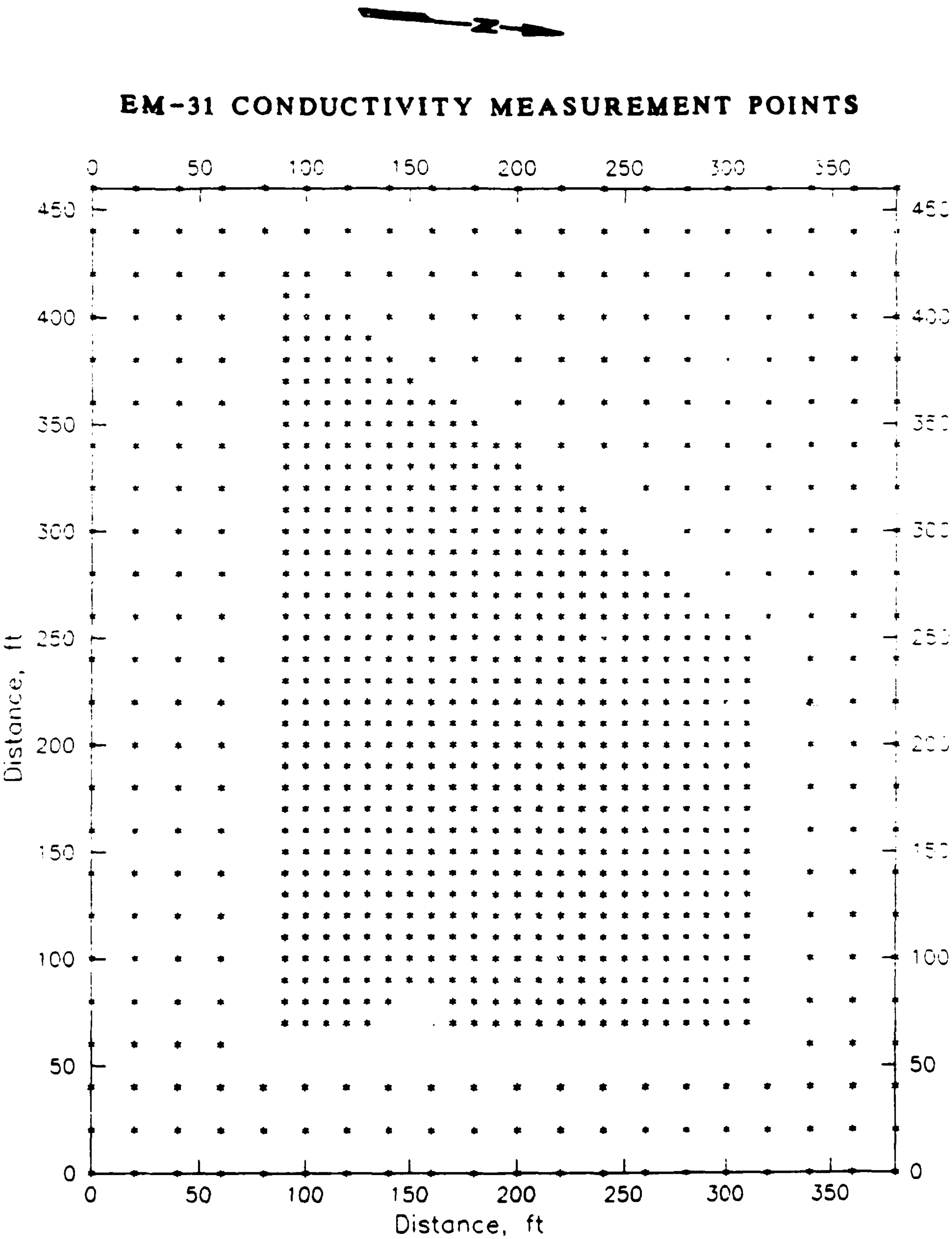

Figure 6. Survey stations for the EM-31 conductivity test.

penetration. Two antennae were tried at the site; 300-Hz and 80-Hz, with the 80-Hz antenna being selected for use throughout the survey. The antenna is mounted on a sled-type device and pulled across the area of interest. In a GPR survey, the data collection consists of a near continuous recording over the area covered by the sled (antenna). For this site, it was decided to make passes through the site along X-direction lines. This procedure was selected due to the nature of the known trenching activity inside the fence. Most of the trenches had their long axis in the Y-direction, which means that the GPR survey was run perpendicular to the trenches. This would give a better chance of intersecting a trench. Outside the fence, passes with the GPR were made at 20-ft (6.1 m) intervals; whereas, inside the fence, passes were made at 10-ft (3.05) intervals. The GPR survey produced 11,800 ft (3597 m) of continuous coverage of the site. A thorough discussion of the survey technique is given in Appendix A.

PART IV: GEOPHYSICAL TEST RESULTS

Magnetometer Results

22. The results of the magnetometer survey are shown in Figures 7-14. Data collected during this study are presented in two formats. Each set of data is presented as a contour map of the measured values and also a three-dimensional view of the surface (block diagram) generated from these contours. Each block diagram has a small orientation figure, located in the lower left corner, which shows the view in the X-Y plane. The data are presented as measured in the field, with a nominal value for the earth's regional field (50,000 nT) subtracted and the drift removed. Figures 7 through 9 present the raw data, Figure 7 is the block representation and Figures 8 and 9 are the contour maps. From Figures 7 and 8, it is apparent that the fence causes a great deal of disturbance as does the bunker. The effect caused by the fence can be seen as sharp peaks and continuous lows affecting magnetic measurements within 25-30 ft (7.6-9.1 m) of the fence. The fence can be outlined by following the consistently low values around the grid. A magnetic object can cause either a high or low value, depending on the orientation of the object and its magnetic susceptibility (thus, the fence is seen as both lows and highs). The mean value after removal of the nominal earth's field value is 4350 nT which provides a reference level for determining significant highs and lows. Three anomalous areas are identified in Figure 8: (1) the area around station (350,400); (2) around station (275,160); (3) around station (130,215). Figure 9 is a contour of the raw data (5-nT intervals) with the area around the fence blanked out. The blanked area consists of 20 ft (6.1 m) each side of the fence. This plot is presented to indicate how much of the area is being influenced by the fence.

23. In an attempt to reduce the effect of the fence on the rest of the data, a filtering process was employed. This involved clipping the high and low values above and below a selected range relative to the mean value. This was done because the values obtained near the fence were so predominantly controlling the scale. Magnetic anomalies in the +/- 20 gamma range could not be established. The data were first filtered by clipping any value that was greater than or less than 1000 nT from the mean. When a value greater than

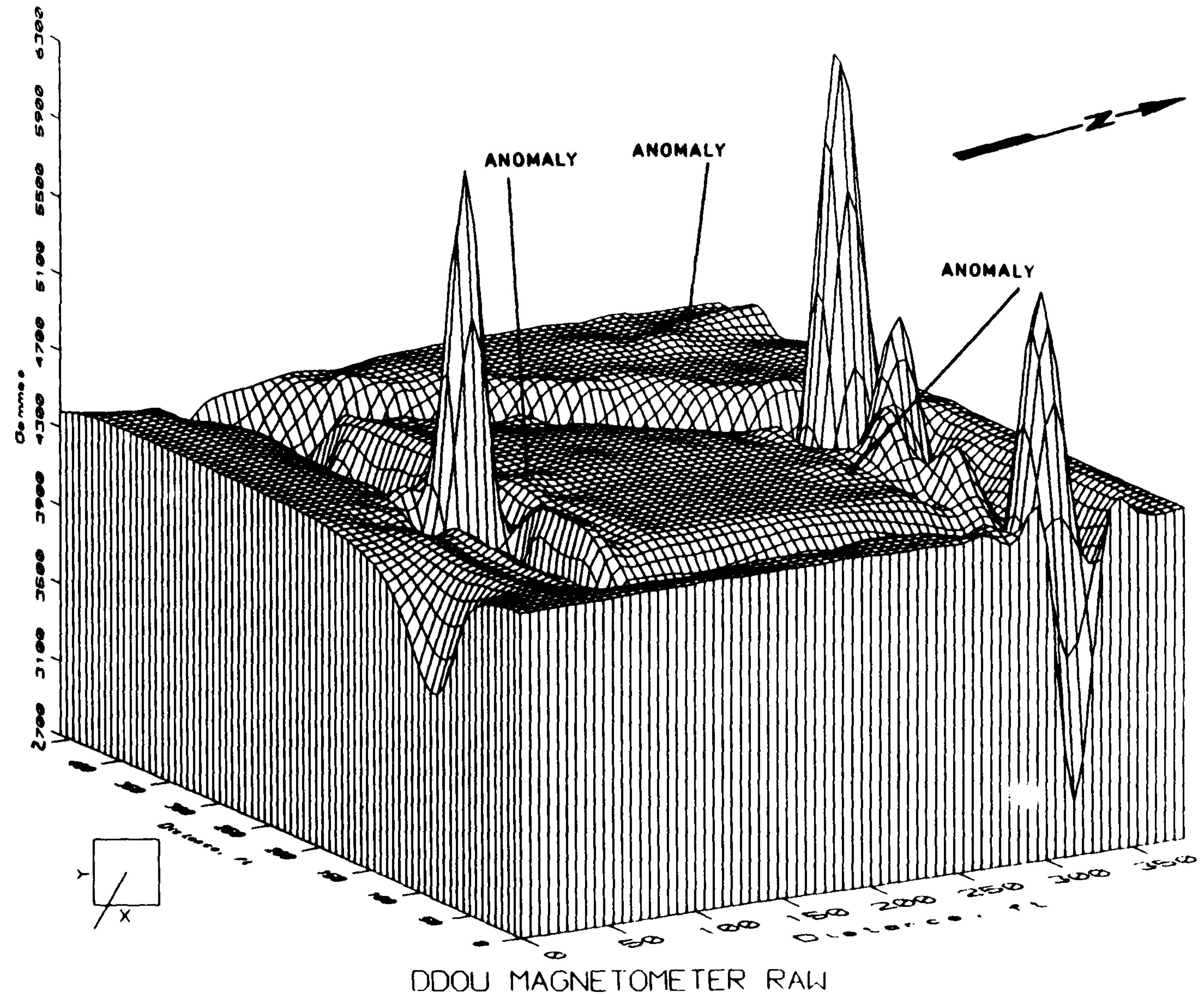

Figure 7. Magnetometer survey test results, block diagram.

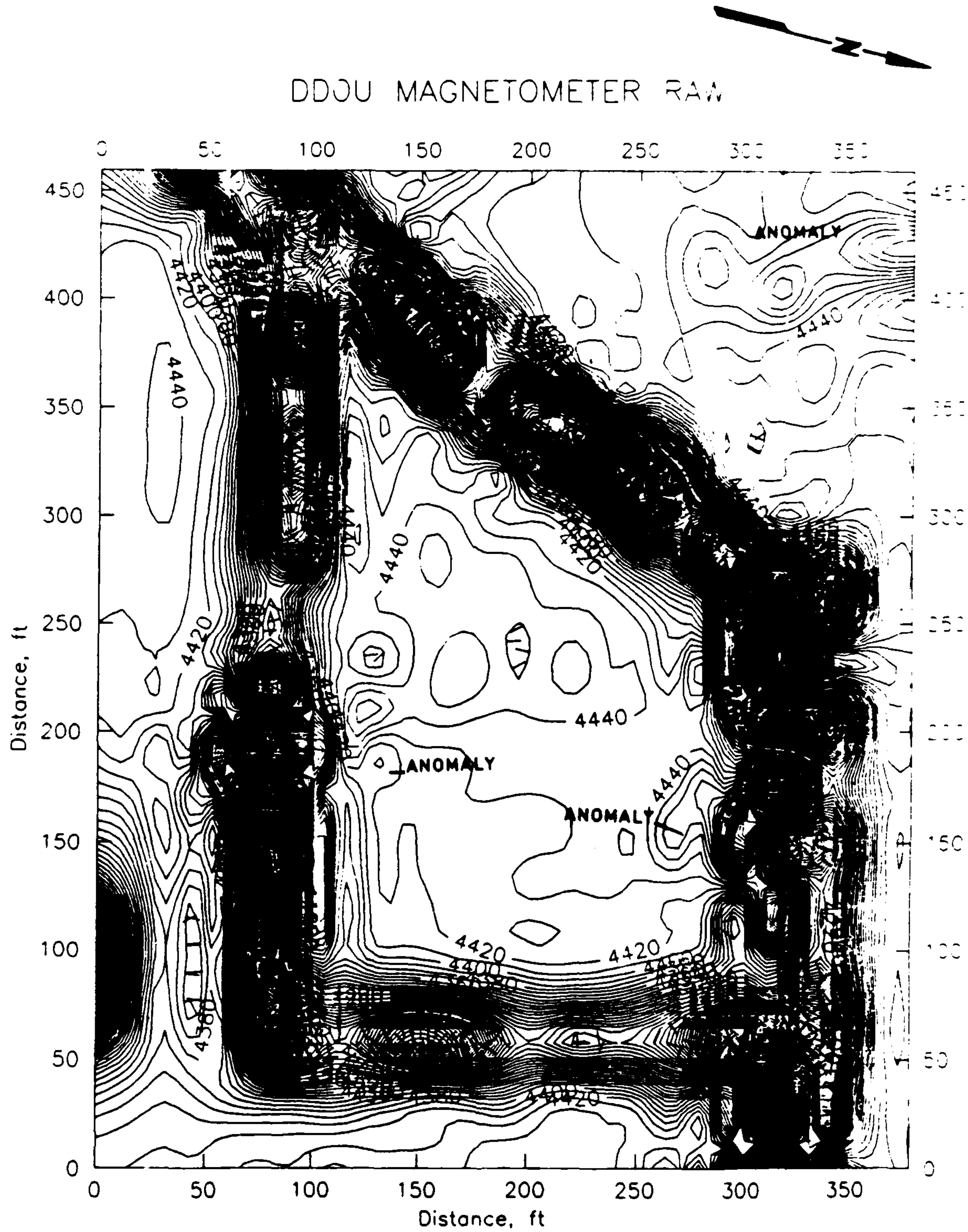

Figure 8. Magnetometer survey test results, contour plot with 10-gamma interval.

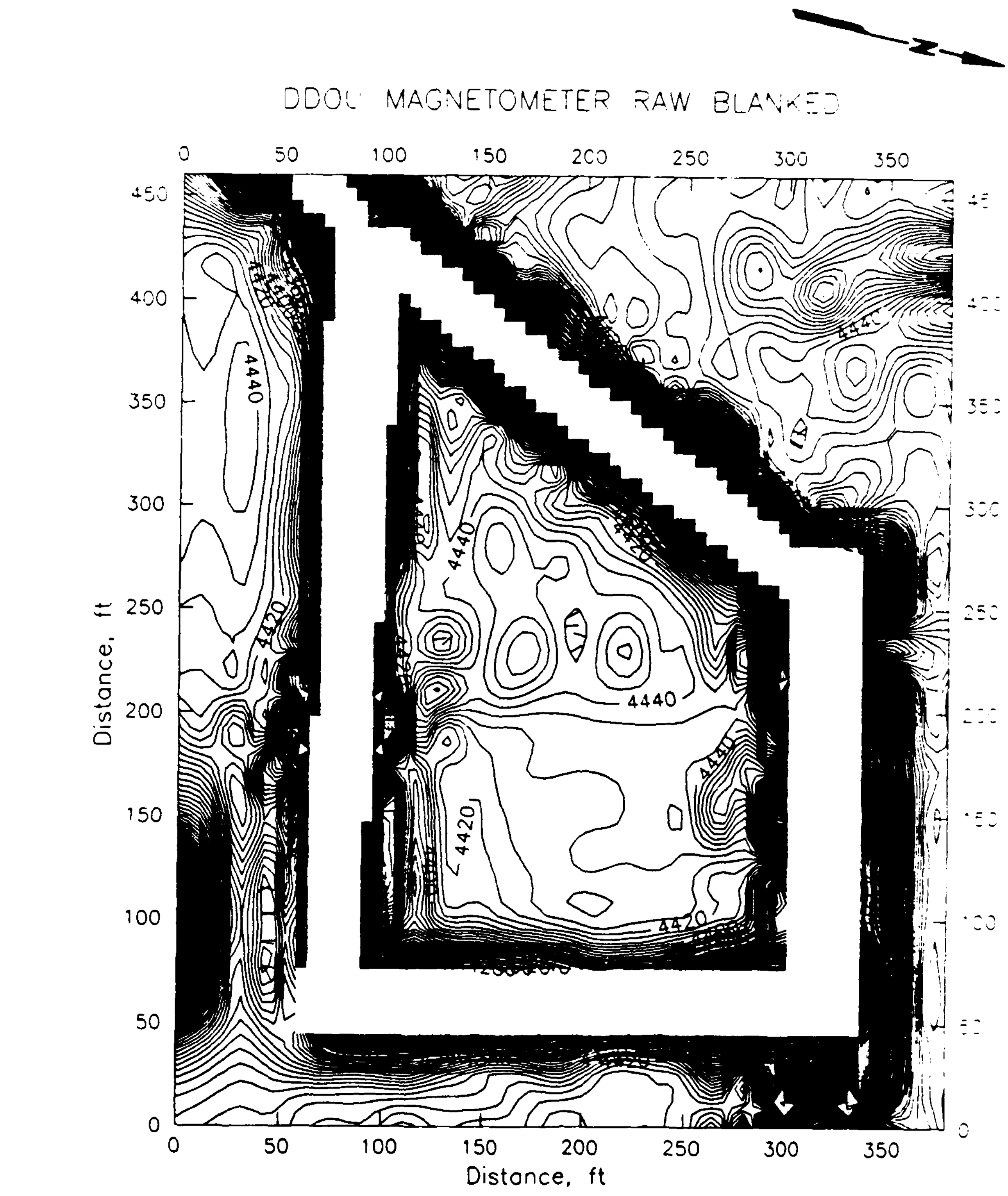

Figure 9. Magnetometer survey test results, contour plot with 5-gamma interval and the fence blanked out.

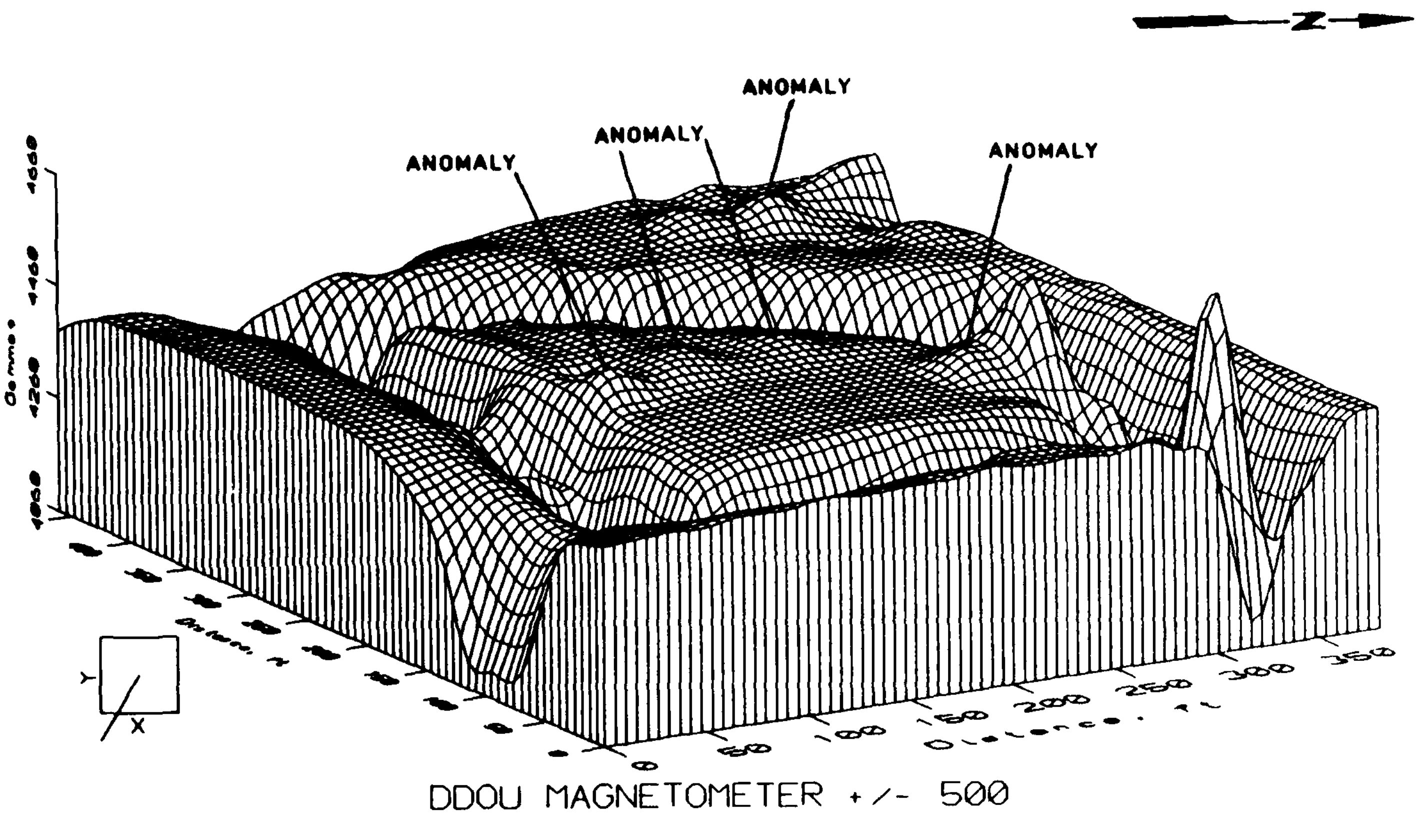

Figure 10. Magnetometer survey test results of the +/- 500 gamma filtered data, block diagram.

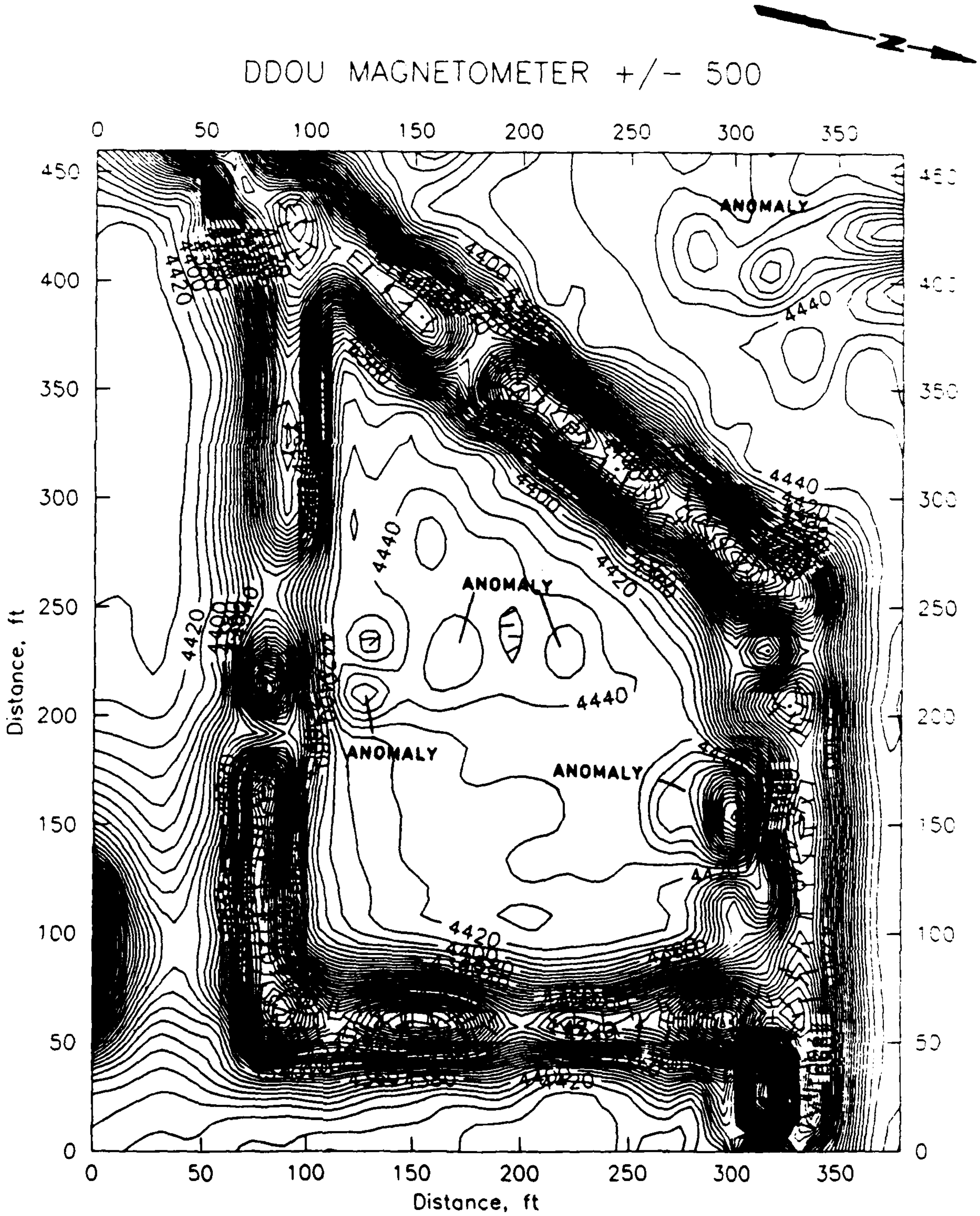

Figure 11. Magnetometer survey test results of the +/- 500 gamma filtered data, contour plot with 10-gamma interval.

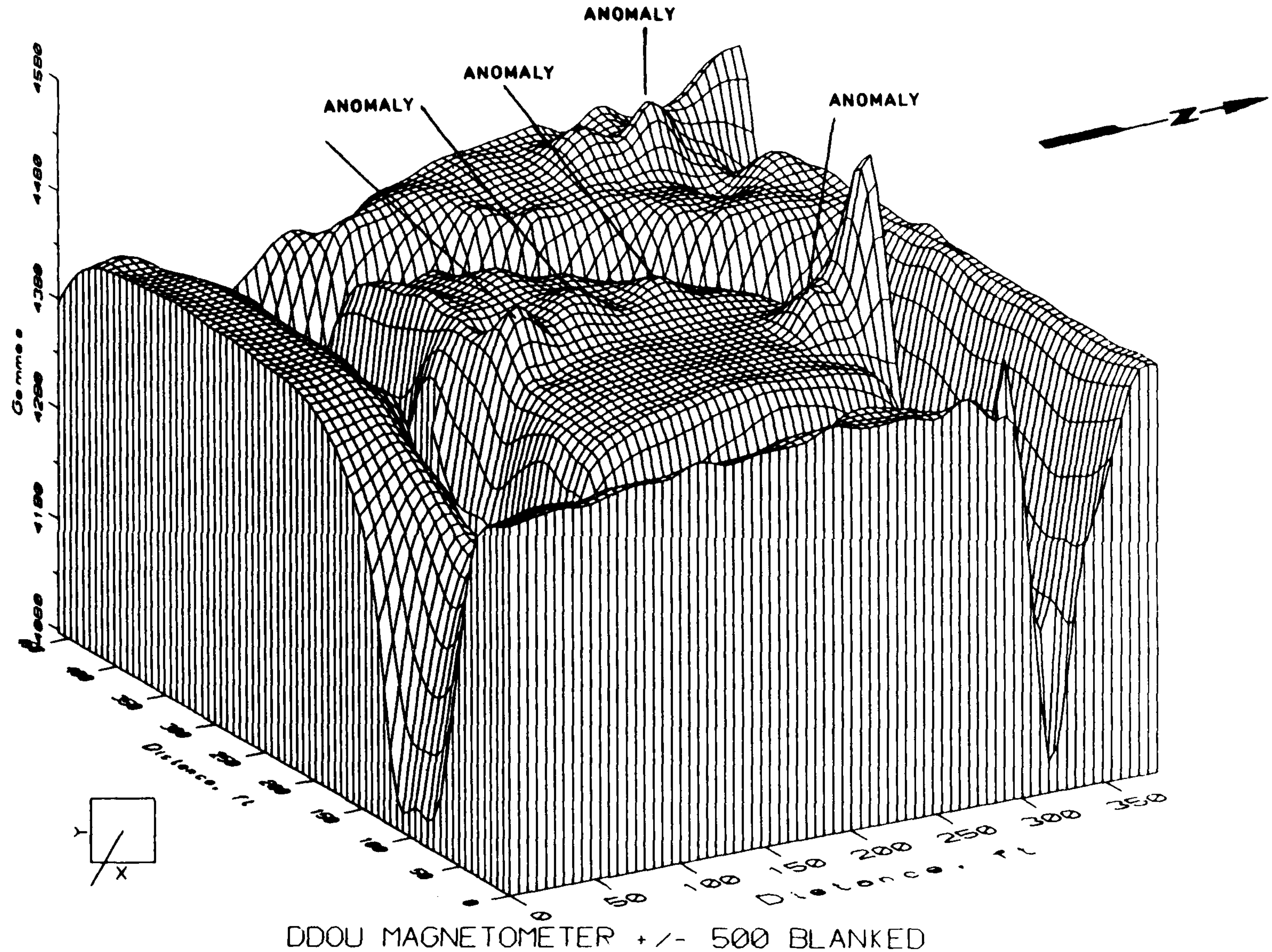

Figure 12. Magnetometer survey test results of the +/- 500 gamma filtered data, block diagram with the fence blanked out.

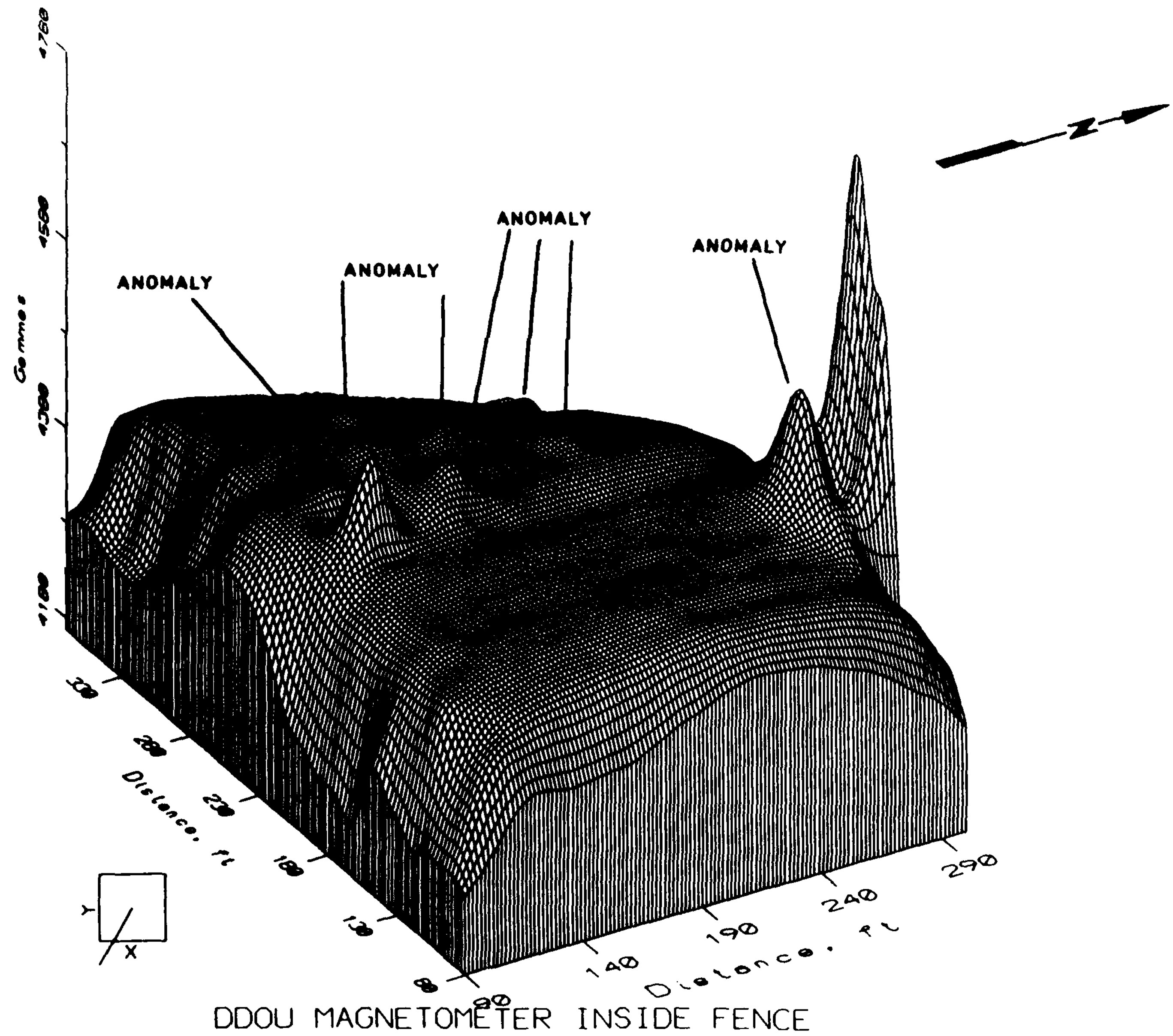

Figure 13. Magnetometer survey test results from the area inside the fence, block diagram.

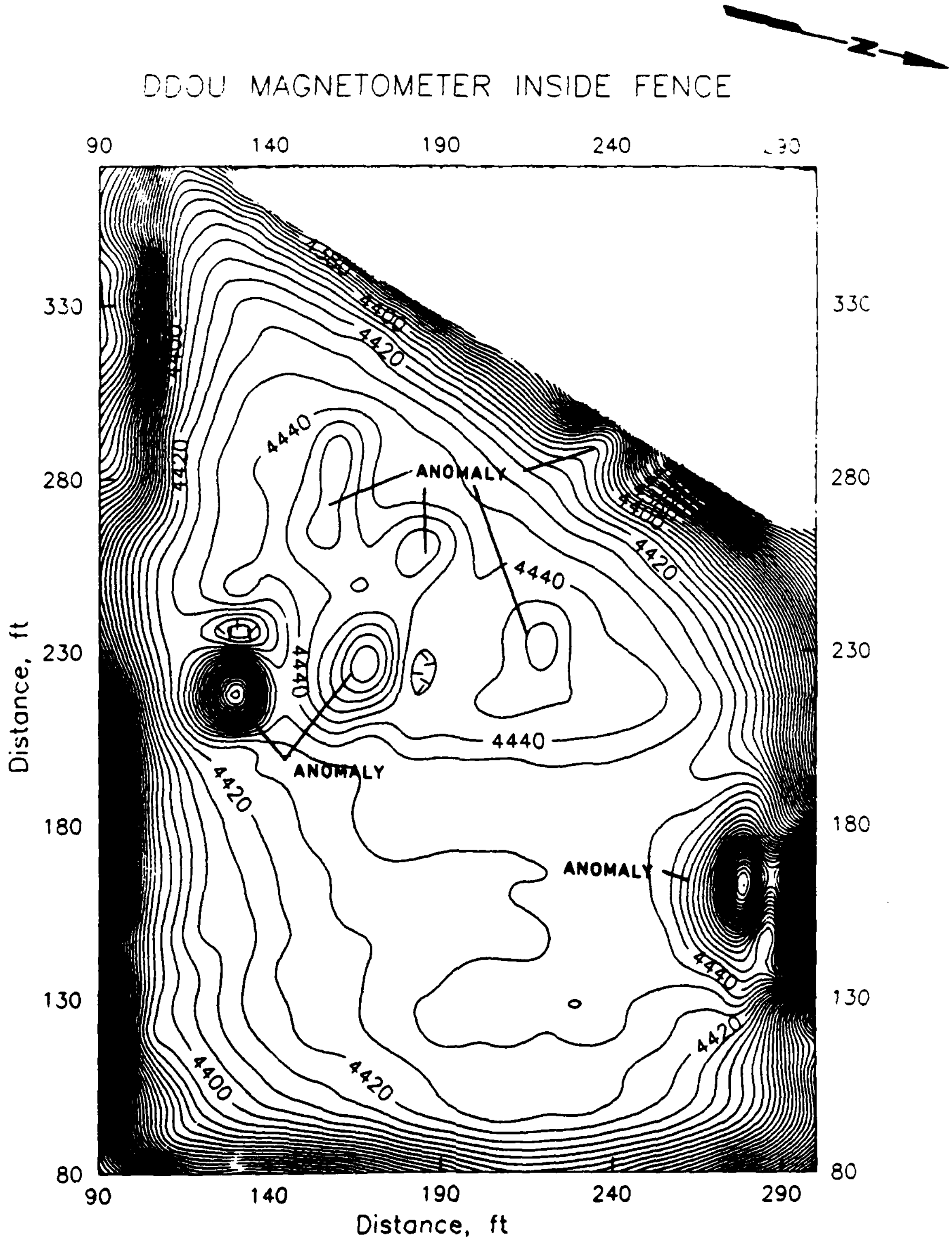

Figure 14. Magnetometer survey test results from the area inside the fence, contour plot with 5-gamma interval.

1000 nT from the mean was found, that reading was set to be 1000 nT above the mean and likewise for negative values. The data were further filtered using a range of +/- 500 gammas from the average. These results are presented in Figures 10 through 12. Figure 12 not only contains the filtered data, but also shows the fence blanked out. By using this filtering and blanking out the fence, the area inside the fence and therefore the anomalies can most effectively be magnified and identified. Filtering below this range tended to nullify the anomalies and be ineffective. From the results of this filtering, several observations can be made (Figures 10-12). The same areas as discussed in paragraph 22 are evident and slightly more visible. Figure 12 presents the best results obtained from the filtering process. Data within 20-ft (6.01 m) of the fence have been blanked out, which allows enhancement of the data for the area inside the fence by enlarging the scale of the entire plot. From this plot, the anomalous areas are very apparent. The locations discussed in paragraph 22 are clearly seen; in particular, the area at location (185,265) is more apparent.

24. The data inside the fence were extracted from the data base and plotted separately; these results are presented in Figures 13 and 14. The fence still affects the data, as evidenced by the low values around the boundary. From this plot seven locations are significant: (130,215), (165,225), (215,230), (185,265), (155,275), (275,160) and (240,290).

EM-31 Results

25. The results of the EM-31 conductivity survey are presented in Figures 15-18. Each set of data is presented as a map of contours of the measured values and also a three-dimensional view of the surface generated from these contours. Figures 15 and 16 are the presentation of the raw field data. There are two observations apparent from the raw data; the fence is once again apparent and appears as highly conductive areas, and the area centered around station (350,400) reveals high conductive values. From this presentation of the data it is very difficult to determine any areas inside the fence that might be indicative of anomalies (conductive zones).

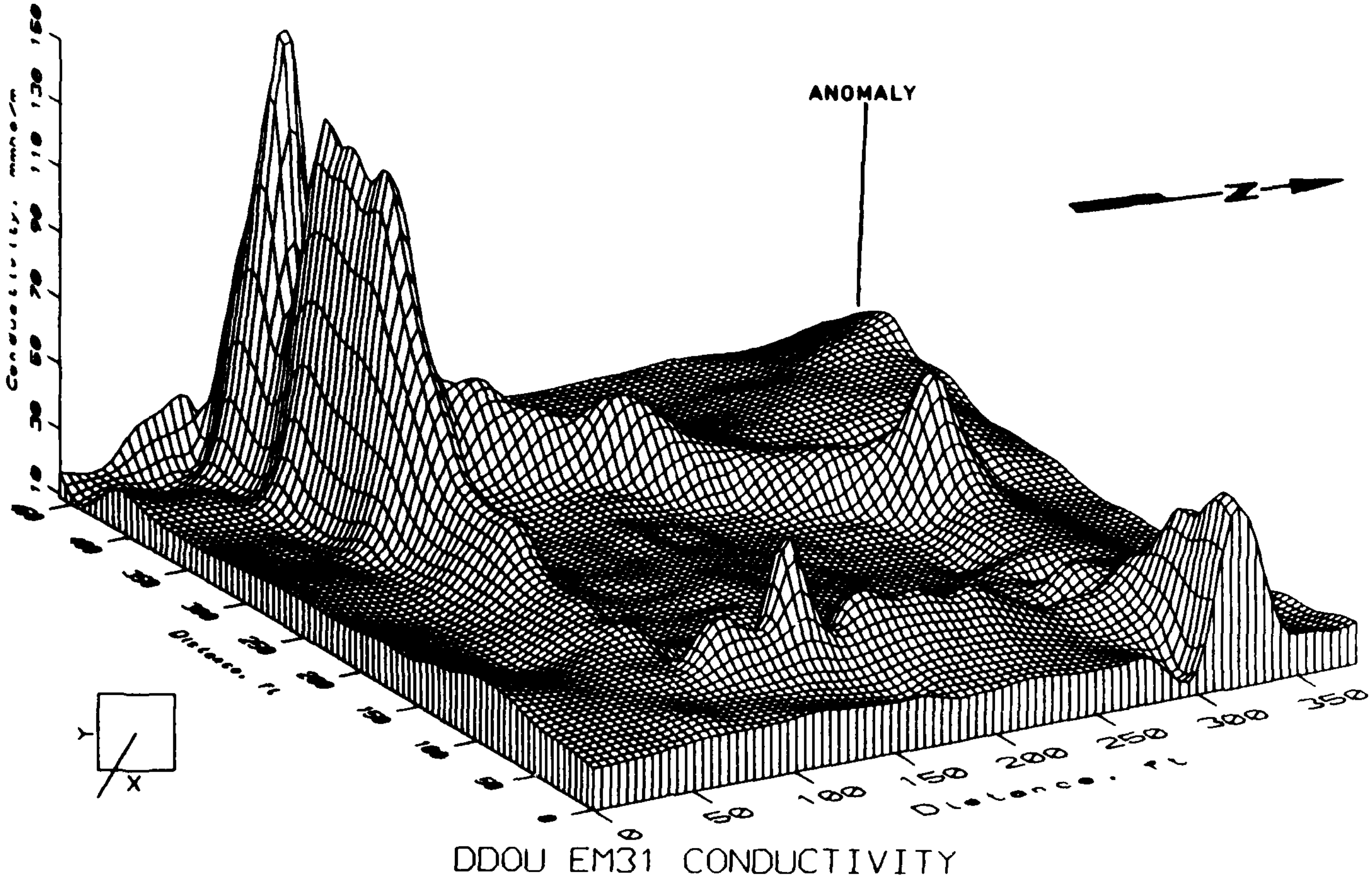

Figure 15. EM-31 conductivity survey test results, block diagram.

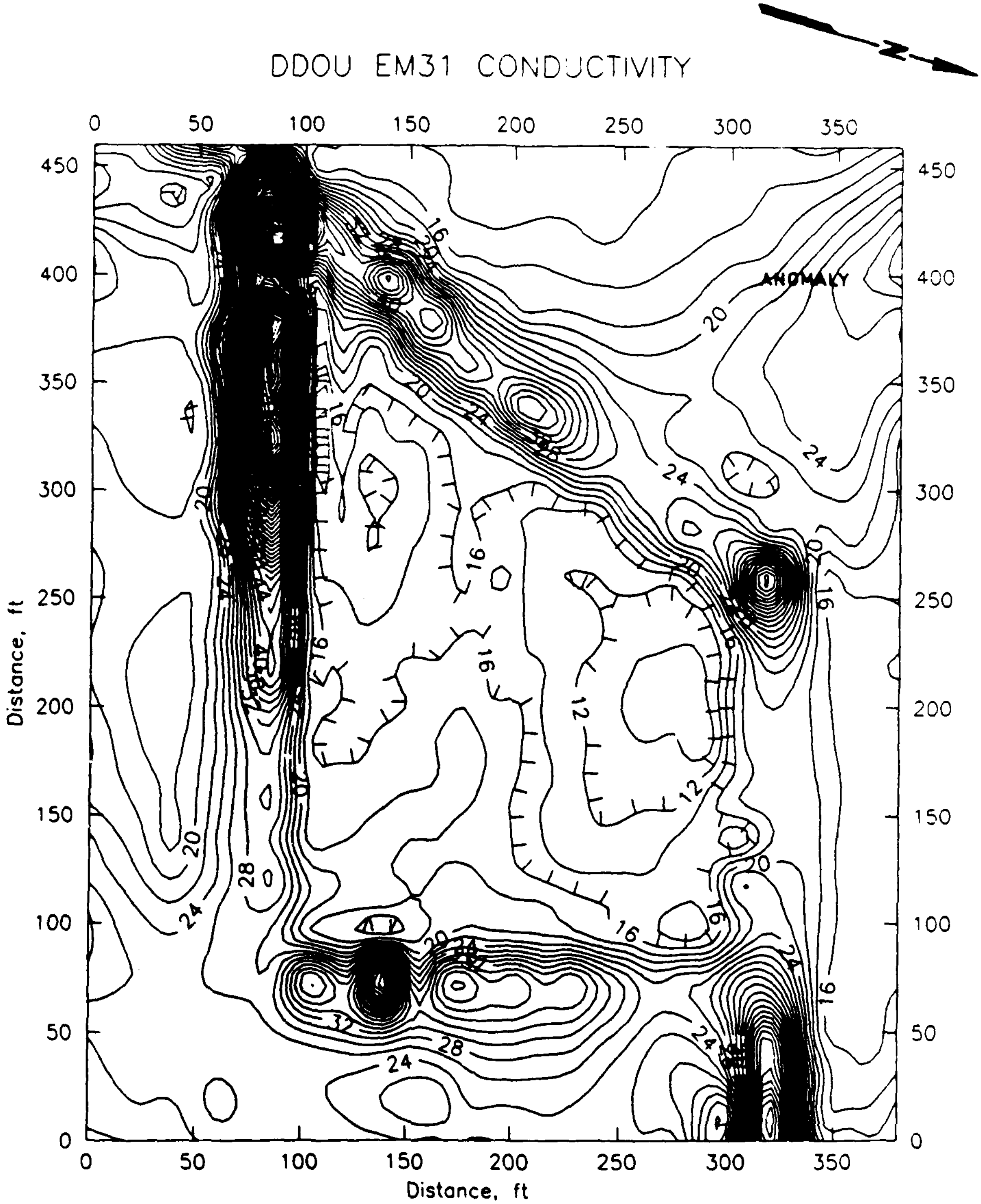

Figure 16. EM-31 conductivity survey test results, contour plot with 2-mmho/m interval.

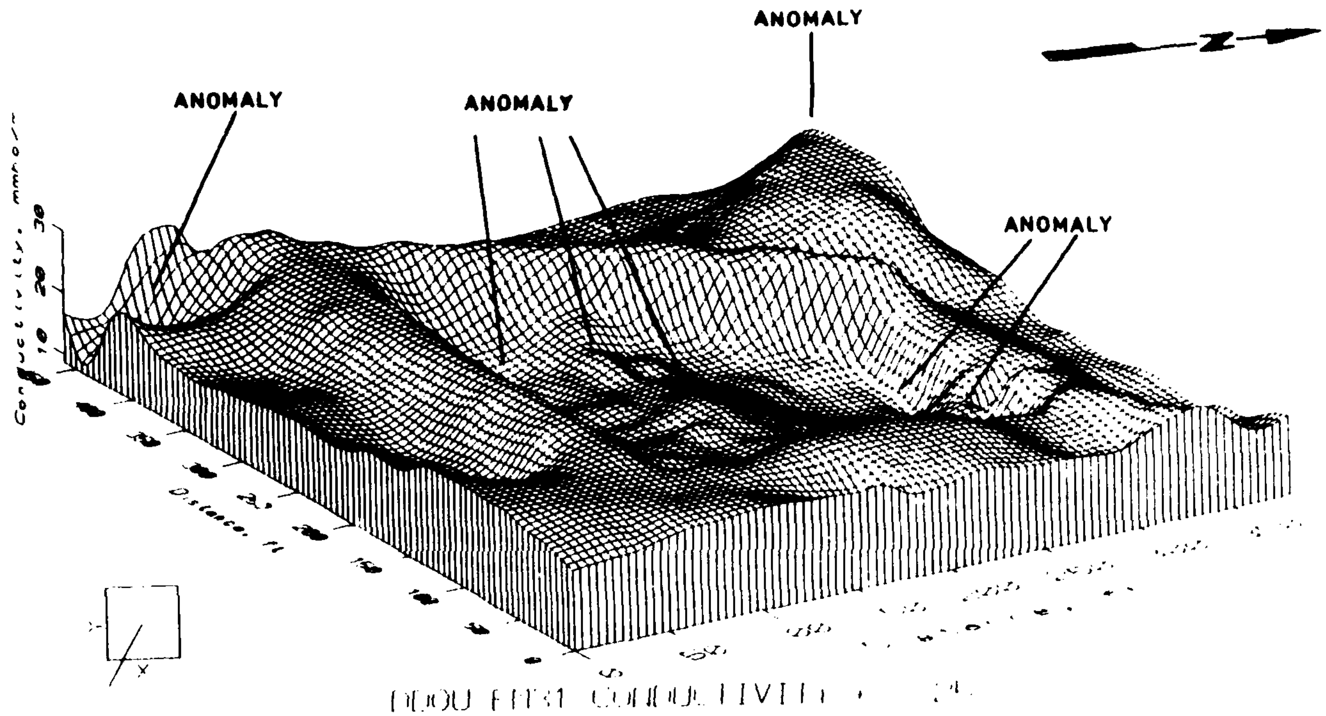

Figure 17. EM-31 conductivity survey test results of the +/- 25 mmho/m filtered data, block diagram.

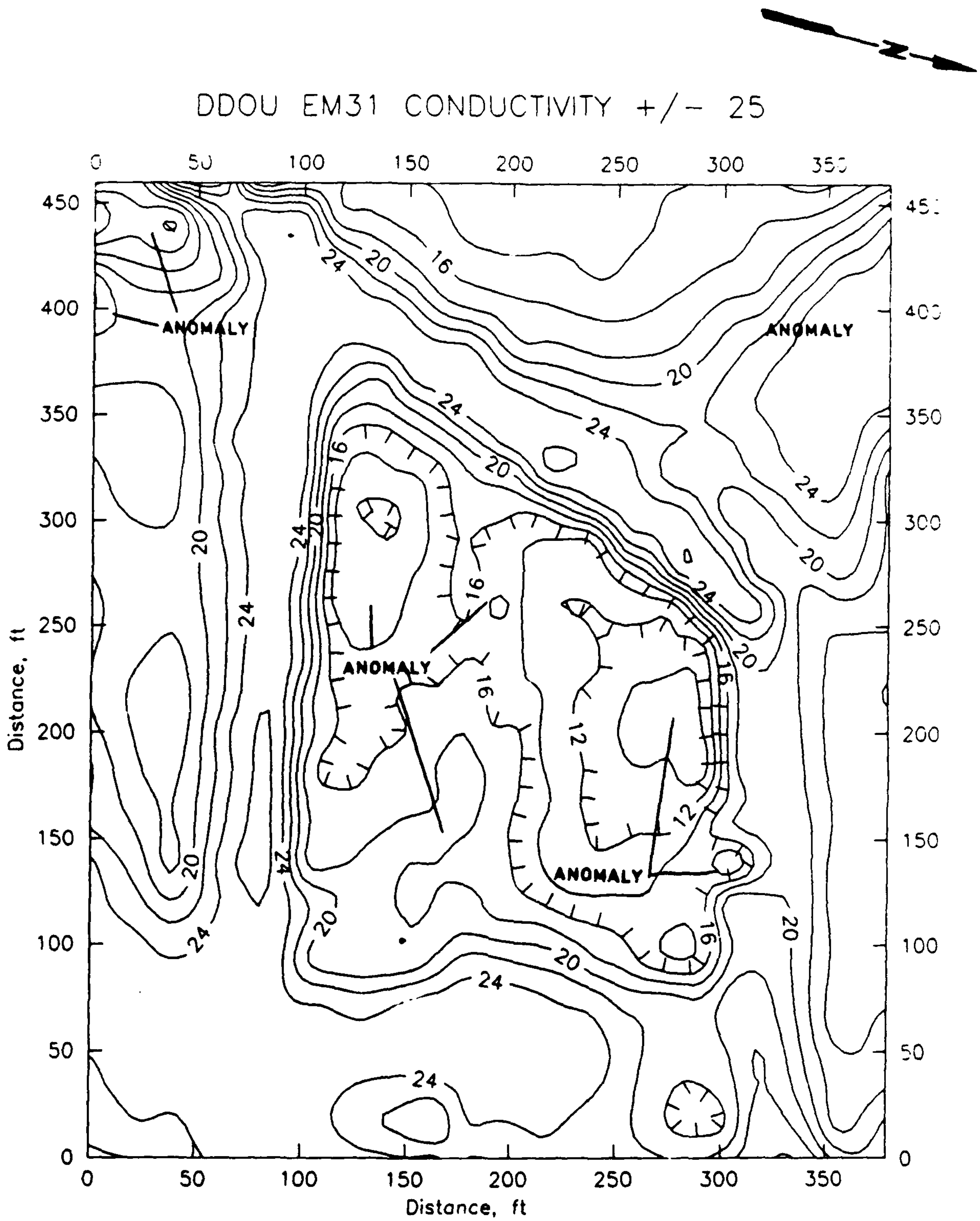

Figure 18. EM-31 conductivity survey test results of the +/- 25 mmho/m filtered data, contour plot with 2-mmho/m interval.

26. To reduce the fence effect and enhance the area inside the fence, a filtering process was employed as described in paragraph 23. The data were first filtered using a value of +/- 50 mmho/m from the average (there are, of course, no values below zero). The data were filtered again using a value of +/- 25 mmho/m from the average (Figures 17 and 18). Several areas begin to become more predominant because the entire plot can be magnified by enlarging the scale. The area at location (350,400) continues to reveal high conductive values and the area at location (20,420) low conductive values. In addition to these two areas, five anomalous locations inside the fence are apparent: (290,125), (270,210), (190,275), (165,165) and (135,310). All of these locations are high conductive zones except for locations (270,210) and (135,310) which are low conductive zones.

EM-38 Results

27. The results of the EM-38 survey are presented in Figures 19-23. As discussed in the field procedures section, the survey was conducted with the instrument in both the vertical and horizontal orientation. The results of the vertical orientation are presented in Figures 19 and 20, and the results of the horizontal orientation in Figures 21 and 22. Figure 23 is a combination of the two surveys with the vertical orientation elevated above the horizontal orientation, for comparative purposes. Results from the vertical orientation reveal several areas that have high conductive values: (290,165), (115,135), (180,135), (160,180), (215,200), (220,255), (140,220-270), (265,210) and (120,310). Several of these locations are seen to correlate with locations from both the magnetometer and EM-31 surveys. There are by far more anomalous regions from this survey than the others due to the relatively shallow depth of investigation of the test. This survey will detect shallow near surface materials with greater sensitivity than the EM-31 and magnetometer. Many of the anomalous regions are indicative of surface material left after the excavation and trenching exercise.

28. The results of the horizontal orientation are very similar to those obtained from the vertical orientation. The following anomalies are identified from the survey: (290,165), (200,120), (105,130), (160,180), (120,180), (220,200), (290,210), (220,260), (170,265), and (120,310). Several

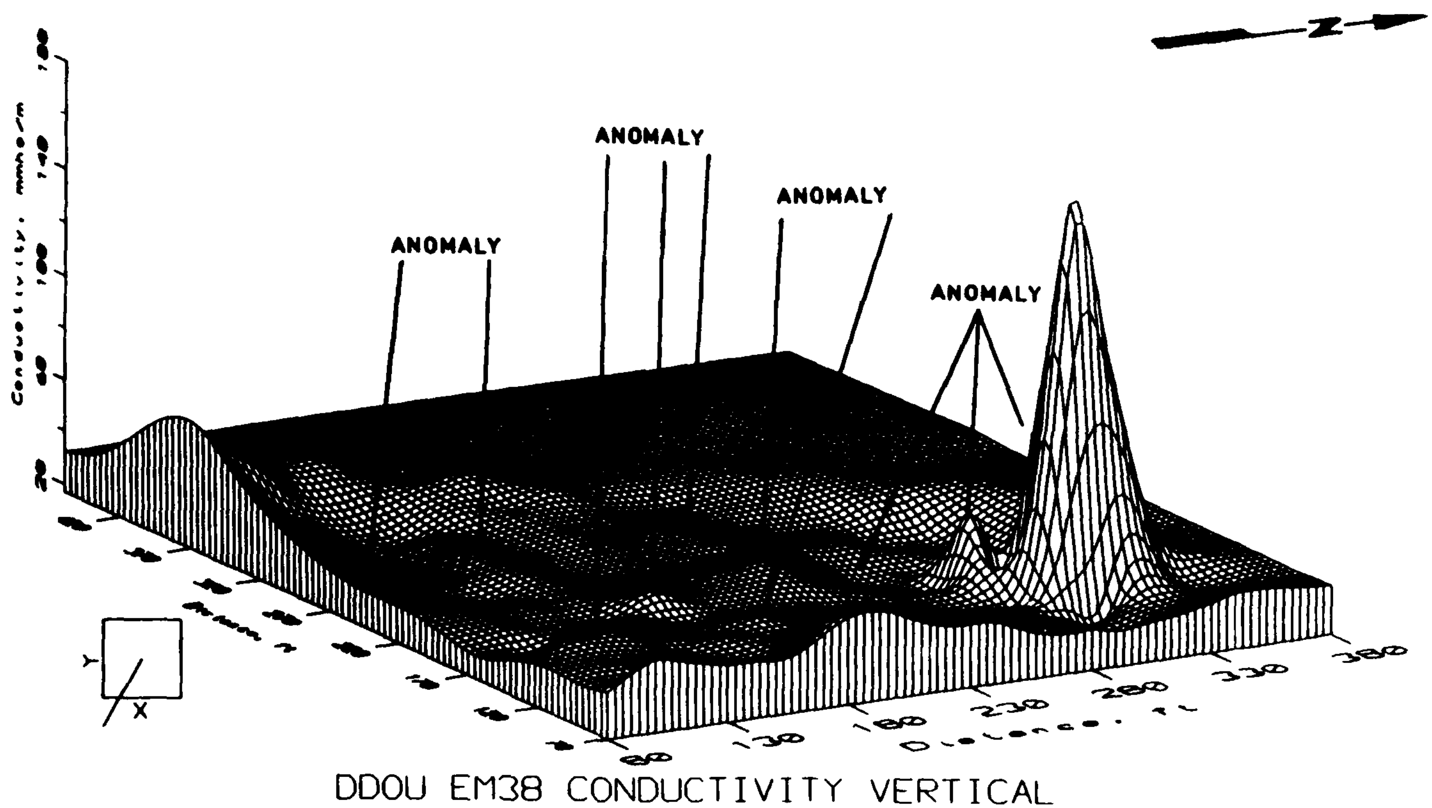

Figure 19. EM-38 conductivity survey test results, vertical orientation block diagram.

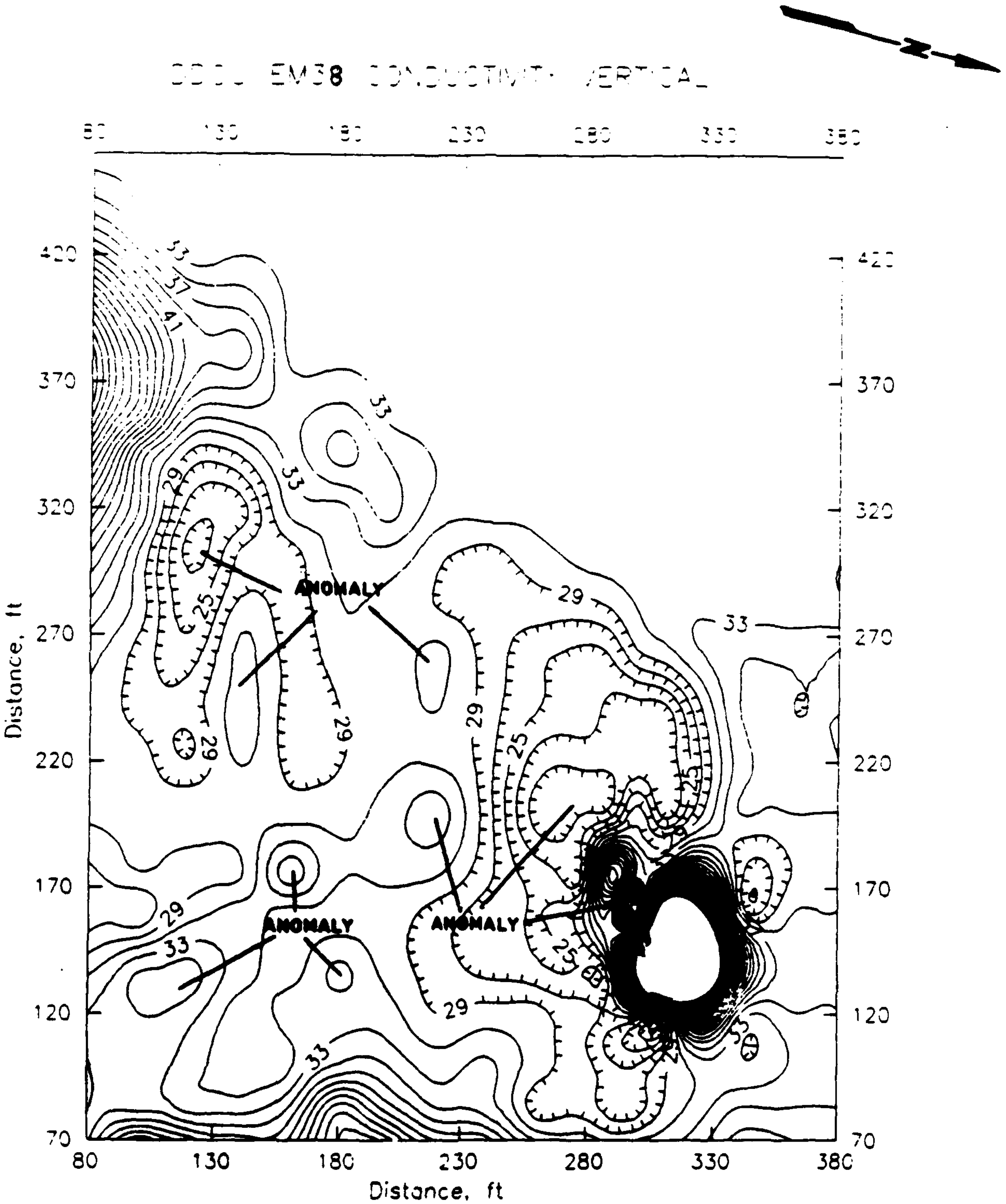

Figure 20. EM-38 conductivity survey test results, vertical orientation contour plot with 2-mmho/m interval.

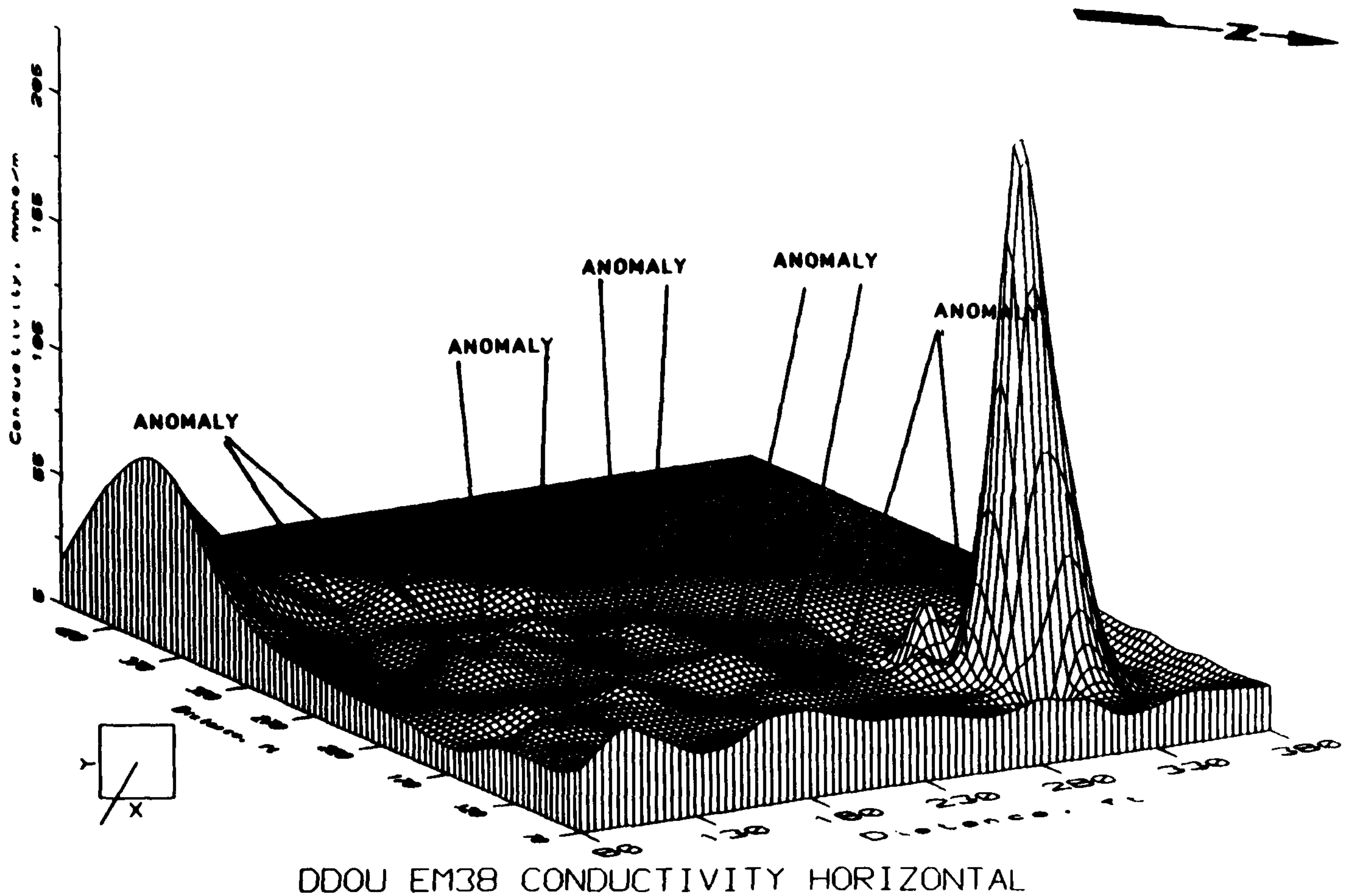

Figure 21. EM-38 conductivity survey test results, horizontal orientation block diagram.

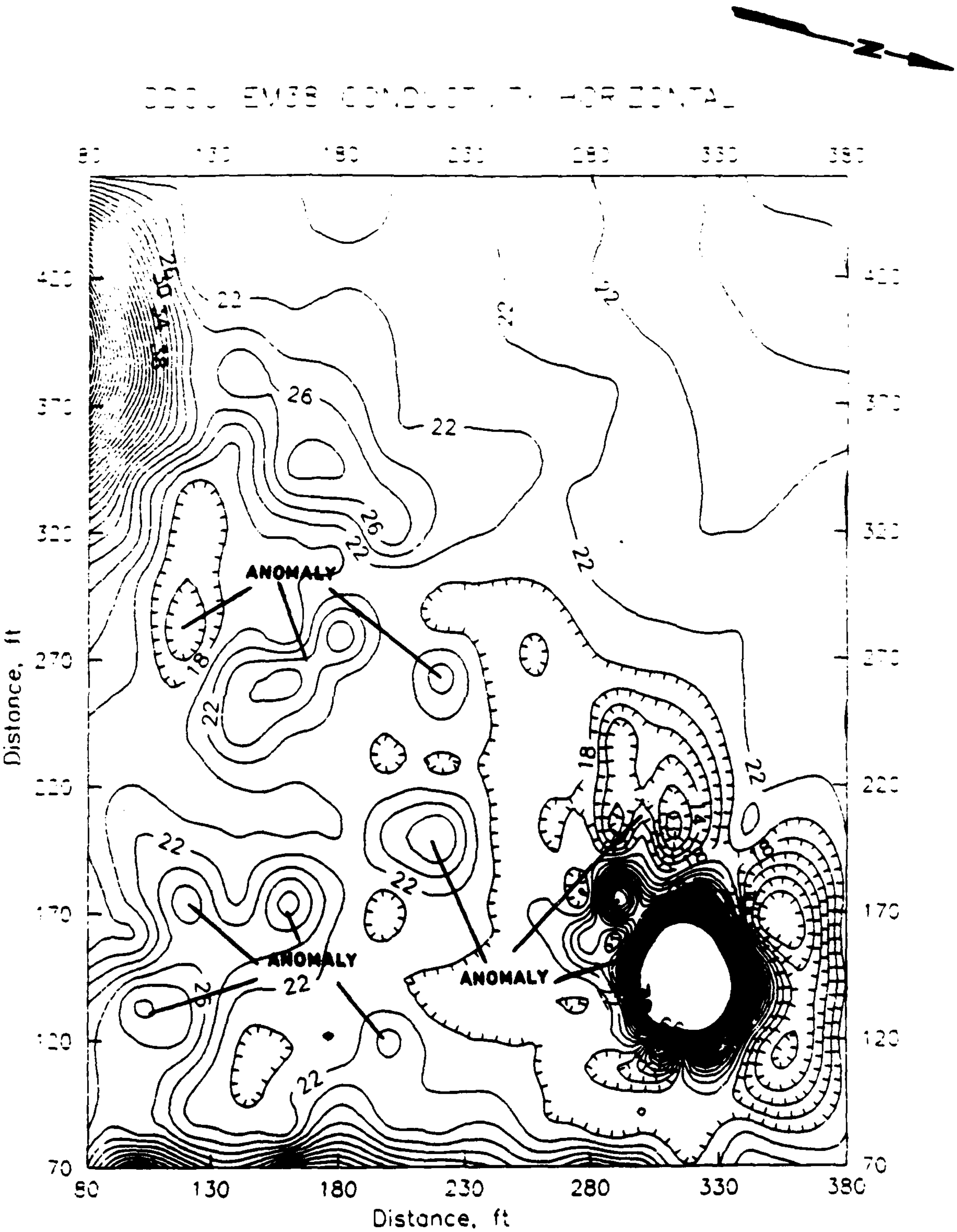

Figure 22. EM-38 conductivity survey test results, horizontal orientation contour plot with 2-mmho/m interval.

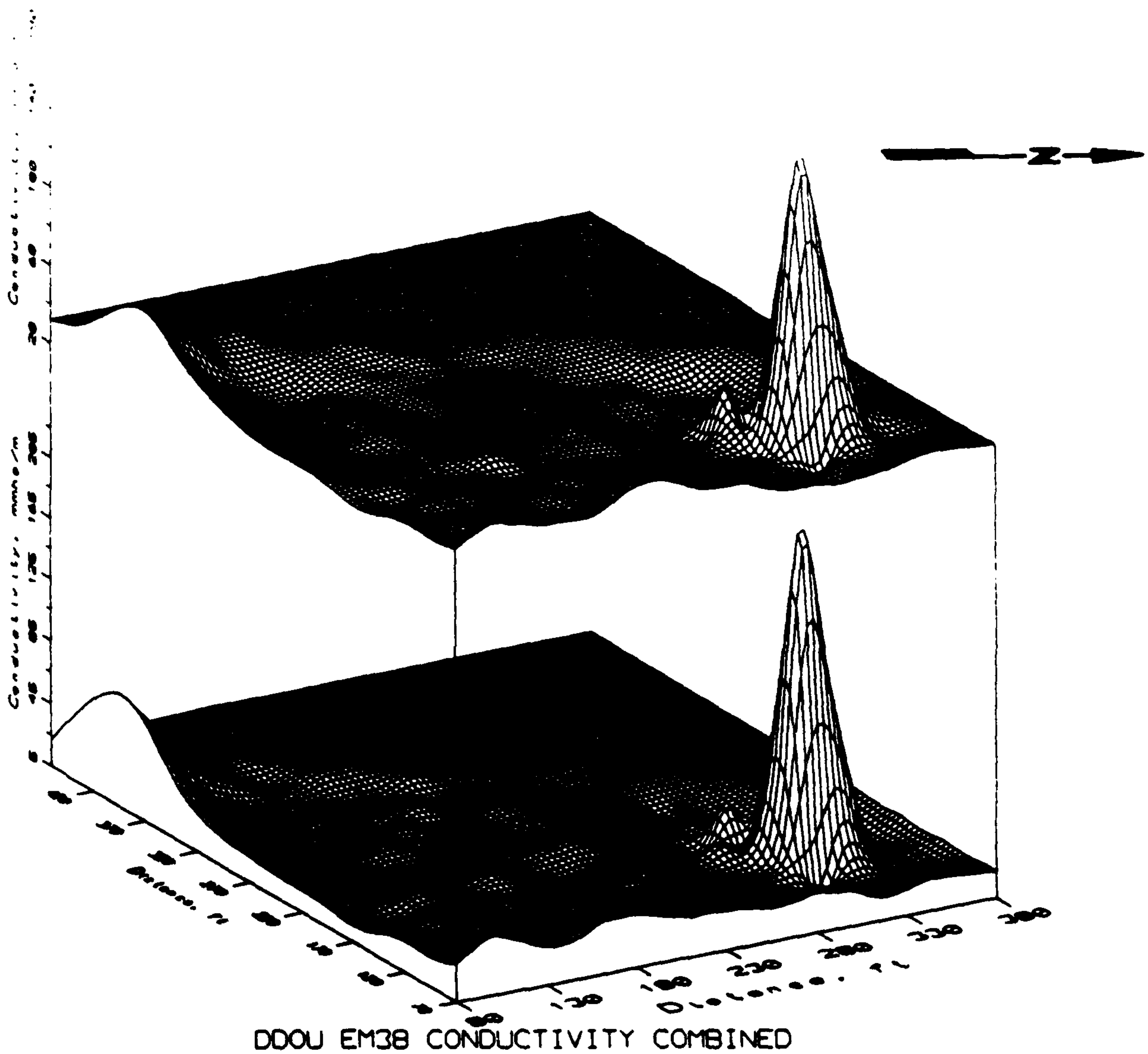

Figure 23. EM-38 conductivity survey test results with the vertical orientation elevated above the horizontal orientation.

of the areas are identical to those detected from the vertical survey, as would be expected. A comparison of the two tests is shown in Figure 23, and can be seen to match almost identically. The horizontal orientation is even more sensitive than the vertical orientation to shallow near surface materials, therefore most of the features detected by the EM-38 are quite shallow.

GPR Results

29. For a complete discussion of the findings and results of the GPR survey see Appendix A. A total of 33 anomalous regions were identified by the radar, 29 are small and isolated with the remaining 4 being about 15 to 20 ft wide (4.6 to 6.1 m). The anomalous regions are identified and shown in Figure 24. The small isolated regions represent man-made objects related tc disposal activities at DDOU. The larger regions may be associated with larger buried material, trenching activity, or localized changes in geologic conditions. The small isolated regions are buried at depths, indicated from the radar data as ranging from 1.0 to 7.5 ft (0.31 to 2.29 m); whereas, the larger regions are buried approximately 4 to 5 ft (1.2 to 1.5 m) below the surface. The exact locations of the regions in the X-Y coordinate system are presented in Appendix A.

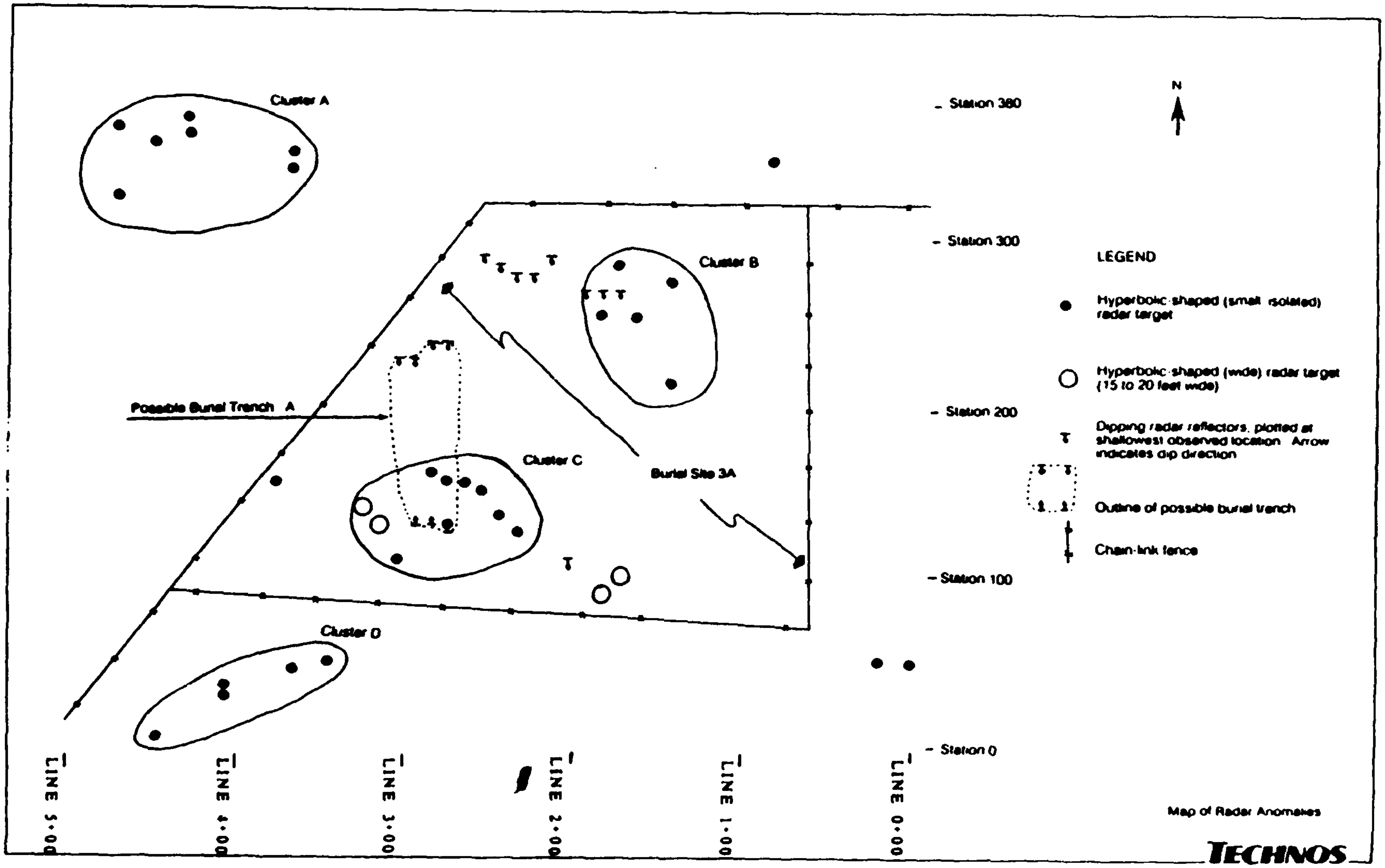

Figure 24. Radar test results with detected target locations (from Technos).

PART V: INTERPRETATION

General

30. In determining which of the anomalous areas from each of the various tests are significant, several factors must be considered. Anomaly detection is limited by instrument accuracy and local "noise" or variation in the measurements caused by factors not associated with the anomalies of interest. For an anomaly to be significant, it must be two to three times greater than these factors. Since the anomaly amplitude and spatial extent (wavelength) are the keys to detection, the size and depth of the feature causing the anomaly are very important factors in determining detectability and resolution. The intensity of the anomaly is also a function of the degree of contrast in material properties between the anomaly and the surrounding material. Based upon the methods employed, noise conditions at the site and the assumption that the target objects are relatively shallow (less than 15-ft or 4.6 m), the areas indicated as anomalous in the "Results" section can be considered as significant. In the interpretation of the results, the following criteria were utilized and only refer to anomalies related to magnetic susceptibility and conductivity. Magnetic lows are not included in the criteria since they are associated with either a magnetic high or an above ground object. Areas indicated as anomalous from the radar survey are used to confirm the presence or absence of objects in the target area. The criteria for anomaly interpretation are:

- Magnetic High and Conductivity High
  Buried metallic objects; possible conductive contaminant waste plume.

- Magnetic High and Conductivity Neutral
  Buried metallic objects, too small or too deep to affect the conductivity measurements.

- Magnetic High and Conductivity Low
  Buried metallic objects; no conductive contaminant waste plume, but some geologic condition producing low conductivity.

- Magnetic Neutral and Conductivity High
  No buried metallic objects; possible conductive contaminant waste plume.

- Magnetic Neutral and Conductivity Low
  No buried metallic objects; no conductive contaminant waste plume, but some geologic condition producing low conductivity.

- Magnetic Neutral and Conductivity Neutral
  No anomalous conditions or buried objects exist, at least to the depth of investigation.

Test Comparisons

31. From the results, a figure has been created that shows the location and approximate size of each anomaly. The magnetic anomalies are shown in Figure 25, the conductivity anomalies in Figure 26, and the radar anomalies in Figure 27. From the magnetic results, eight areas have been identified as being significant. Each one of these areas revealed high magnetic readings in excess of 50 gammas from the mean, which is quite significant given the nature of their locations (relatively low noise areas). The locations of the areas along with brief descriptions are given below.

Location	Description
(350,400)	Large area that contained several anomalies centered about this location.
(275,160)	High magnitude anomalous area close to fence but not caused by fence.
(240,290)	Small area close to but not caused by the fence.
(215,230)	Small area localized target.
(185,265)	Small area localized target.
(165,225)	Small area localized target.
(155,275)	Small area localized target.
(130,215)	Small area localized target.

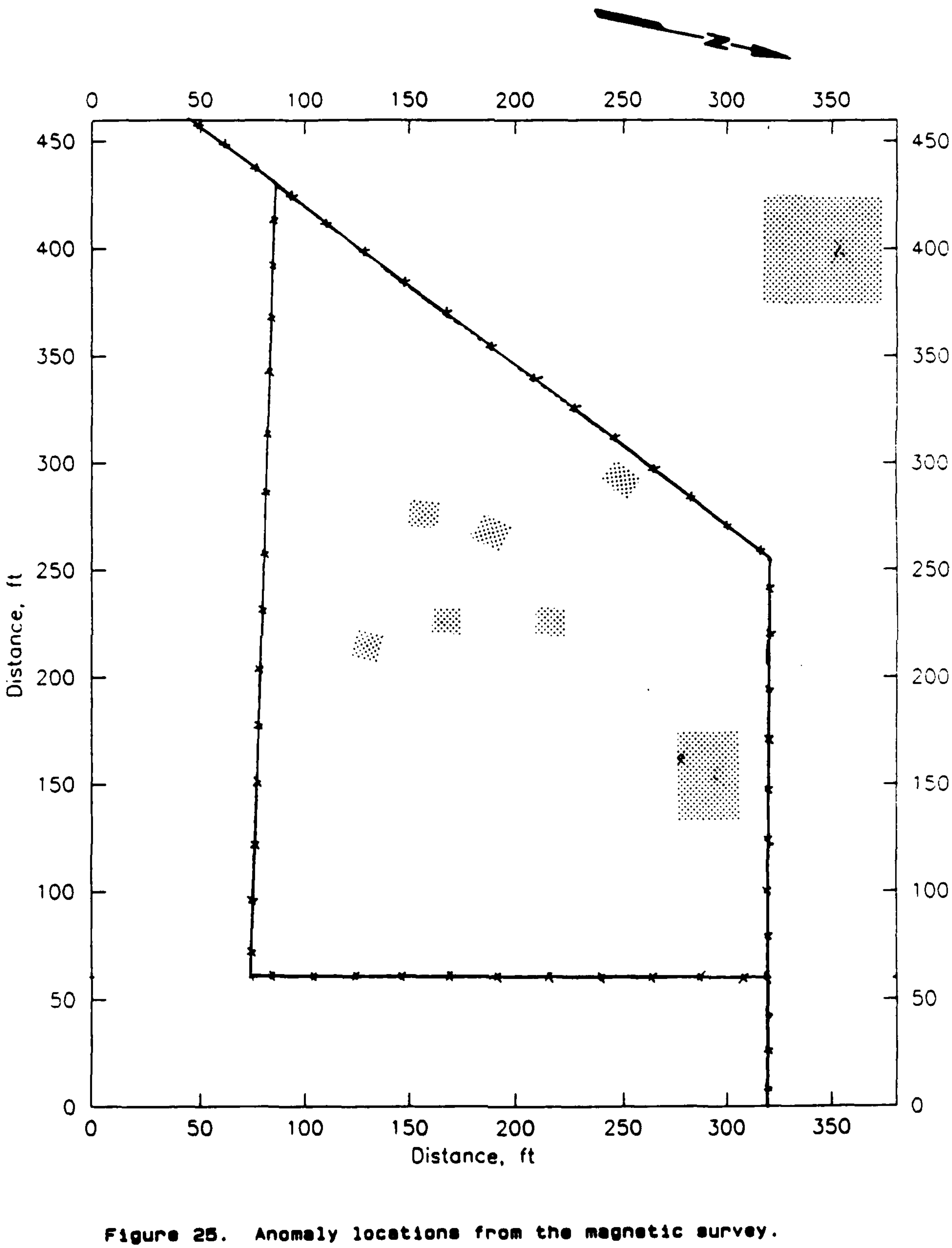

Figure 25. Anomaly locations from the magnetic survey.

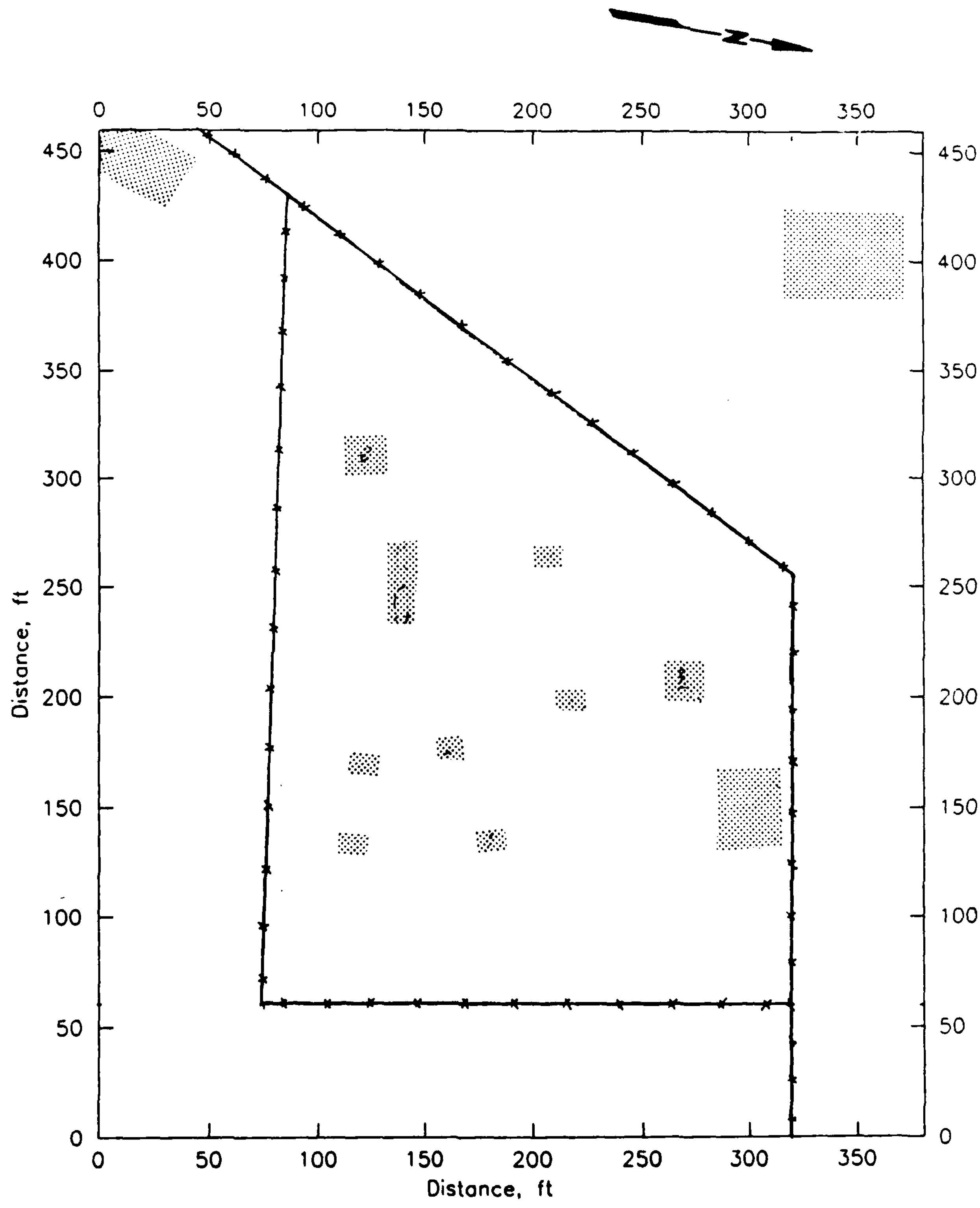

Figure 26. Anomaly locations from the conductivity surveys.

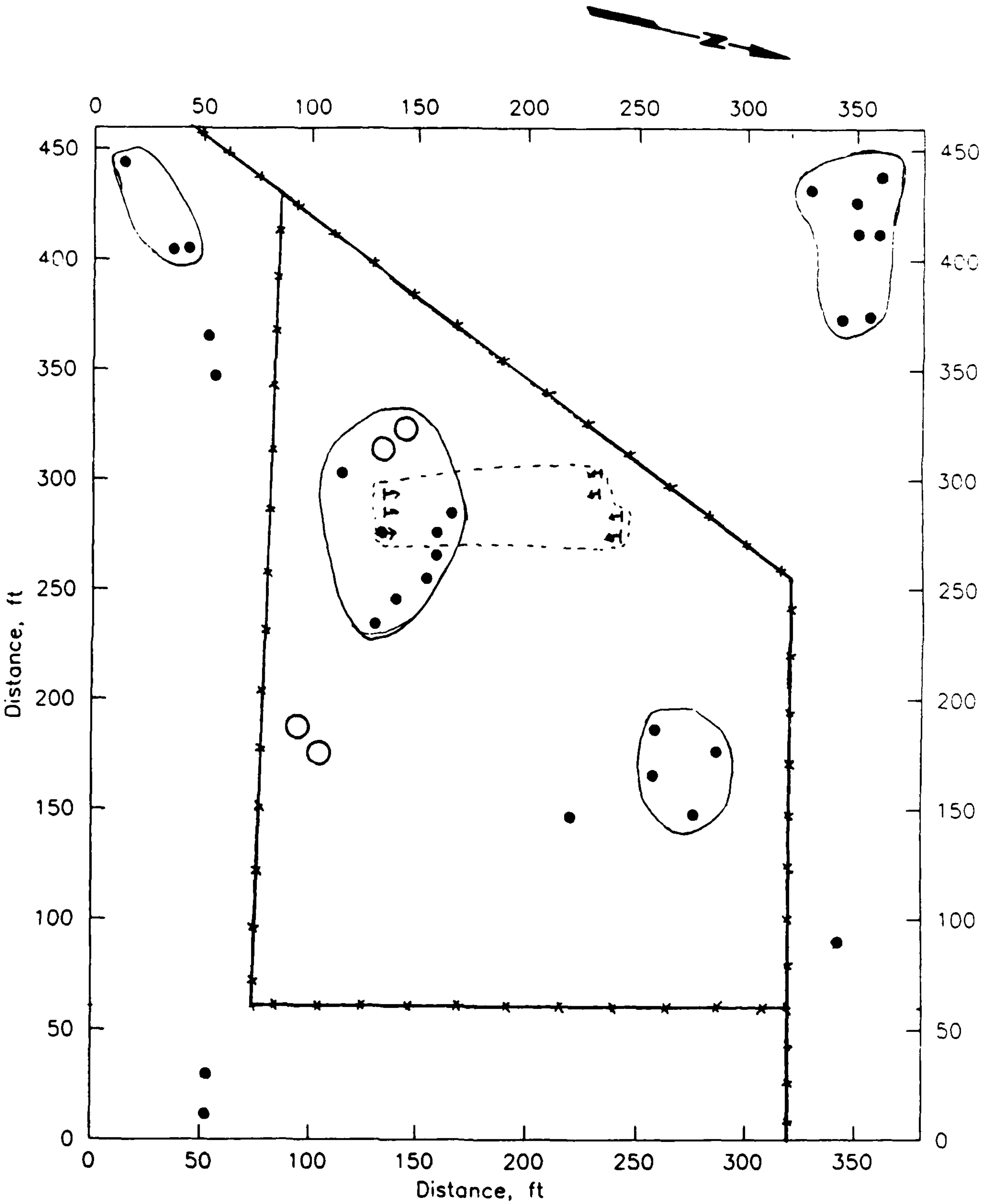

Figure 27. Radar test results with detected target locations.

32. Anomalies for all three of the conductivity tests, EM-31, EM-38 horizontal (EM-38H) orientation, and EM-38 vertical (EM-38V) orientation have been combined in Figure 26. There are a total of 12 areas identified in the figure, with their locations and descriptions presented below.

Location	Description
(350,400)	EM-31 survey only, large area with high conductivity readings.
(295,160)	Detected by all three tests, large area with high readings.
(275,210)	Detected by all three tests,medium size area with low conductivity readings.
(220,260)	Detected by all three tests, small area localized target.
(125,310)	Detected by all three tests, medium size area with low conductivity readings.
(110,130)	EM-38H and EM-38V tests only, small area localized target.
(160,180)	EM-38H and EM-38V tests only, small area localized target.
(220,200)	EM-38H and EM-38V tests only, small area localized target.
(190,130)	EM-38H and EM-38V tests only, small area localized target.
(150,220-270)	EM-38H and EM-38V tests only, long narrow area.
(120,180)	EM-38H test only, small area localized target.
(20,420)	EM-31 test only, large area with low conductivity readings.

33. The interpretation of the radar results is presented in Figure 27. These are the same results as shown in Figure 24, and presented in Appendix A. Most of the areas indicated in the figure are small isolated targets and have been grouped together to form larger anomalous areas of interest. The four areas that have been circled are the most significant and correspond to anomalous areas identified by the other tests. The area encompassed by the dashed line is a possible trench location.

34. An integrated anomaly map for all the tests results is presented in Figure 28. Each area identified in Figure 28 was selected because it appeared in at least two of the different tests conducted. The location of each area and a brief description is given below.

Location	Description
(280,150)	Area has magnetic high, conductivity high and radar concurrence. Possible buried metallic objects.
(350,400)	Area with magnetic high, conductivity high and radar concurrence. Possible buried metallic objects.
(230,290)	Area with magnetic high and radar indication of possible trench activity. Possible buried metallic objects.
(200,270)	Area with isolated magnetic highs and isolated conductive highs and indication of possible trench activity from the radar. Possible metallic objects.
(130,270)	Area with isolated magnetic highs, isolated conductive highs and lows, and radar concurrence. Chance of metallic objects.
(20,420)	Area with low conductivity and radar concurrence. Possibly some buried objects that are not magnetic.

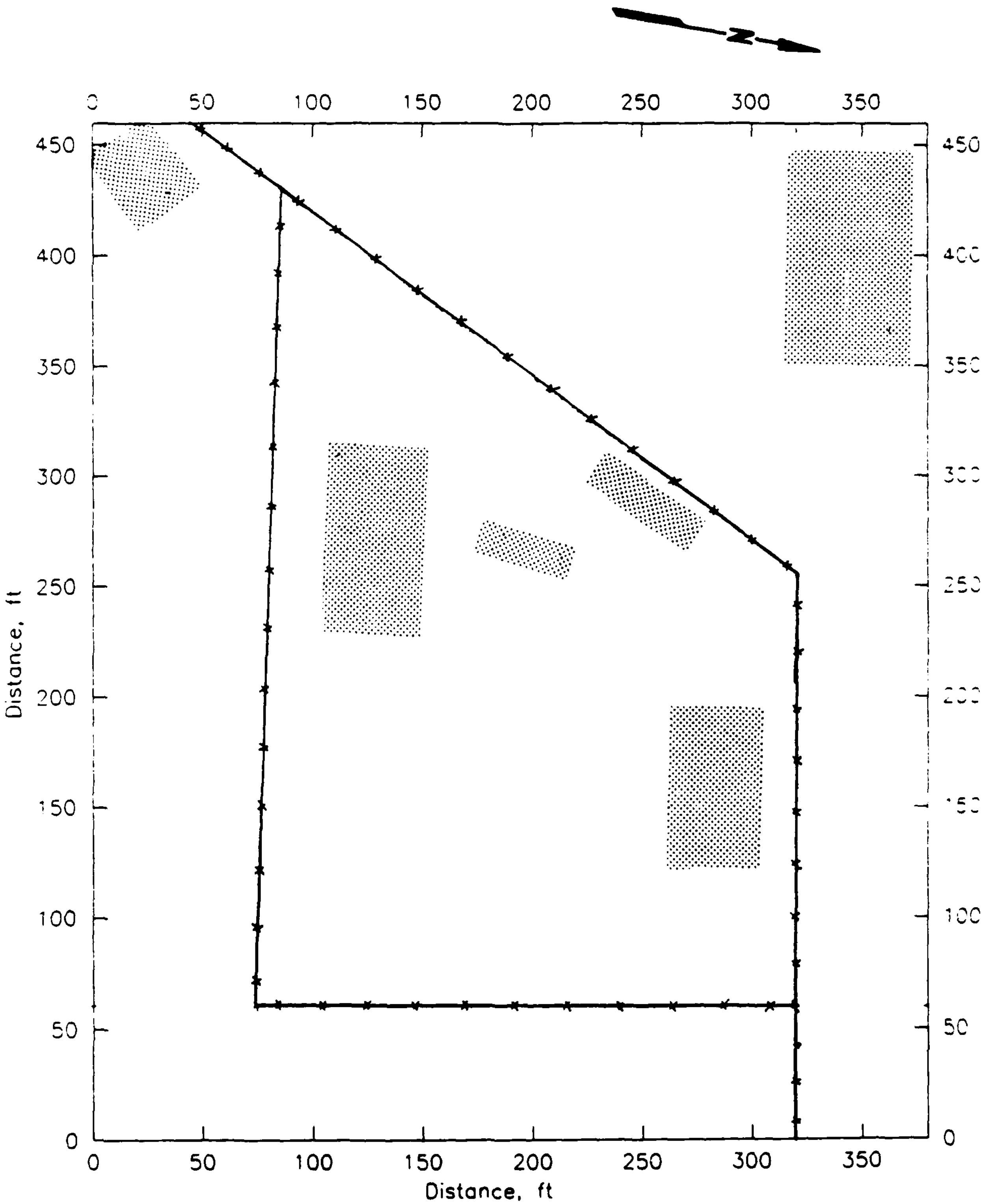

Figure 28. Composite of all tests, with anomalous area locations.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

35. Recommendations for further investigations are: (1) highest priority to those areas identified in Figure 28; (2) lower priority to the small, isolated targets identified from each test and identified on previous figures, but not shown in Figure 28. It should be pointed out that the areas identified inside the fence (Figure 28) are coincidental with previous trenching activity (Figure 2), and some of the materials at these locations are known. The two areas outside the fence have not undergone any previous trenching activity and show strong indication that unidentified, anomalous materials or conditions exist in these areas.

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APPENDIX A:

RADAR SURVEY, DEFENSE DEPOT

OGDEN, UTAH

TECHNOS, INC.

FINAL REPORT

Ground Penetrating Radar Survey

at Burial Site 3A

Defense Depot Ogden, Utah

For

U. S. Army Waterways Experiment Station
Corps of Engineers
Vicksburg, Mississippi

December 22, 1989

TECHNOS Project No. 89-142
Contract No. DACA 3990M0084

Submitted by:
Technos Inc., Consultants in Applied Earth Sciences,
Miami, Florida

I. TABLE OF CONTENTS

II. LIST OF TABLES AND FIGURES

1. BACKGROUND

Defense Depot Ogden, Utah (DDOU) is a Defense Logistics Agency Depot located in Ogden, Utah (Figure 1). One of the depot's main responsibility is the storage and handling of various military related chemical agents which include US Military Chemical Surety Materials (CSM).

Burial Site 3A is a site located in the southwestern portion of DDOU. Disposal activities are known to have occurred at Burial Site 3A (Per. Comm. Dwain Butler). A review of DDOU past waste management practices by USATHAMA indicates that burial trenches in Burial Site 3A are no more than 2 meters deep.

During the period May 16, 1988 to June 2, 1988, US Army Technical Escort personnel from Dugway Proving Grounds, Utah excavated test trenches and pits at suspected locations within Burial Site 3A. They found several potentially hazardous materials which included a compressed gas cylinder, a 55-gallon steel drum, numerous US military "M-18" chemical agent detection kits, and numerous small metal containers (Per. Comm. Dwain Butler).

It is believed that Burial Site 3A may contain potentially hazardous materials in additional to those excavated by US Army Technical Escort personnel. Further, aerial photo analysis indicates that disposal of military related items may have also occurred in the area immediately surrounding Bu[illegible] Site 3A (Pers. Comm. Dwain Butler).

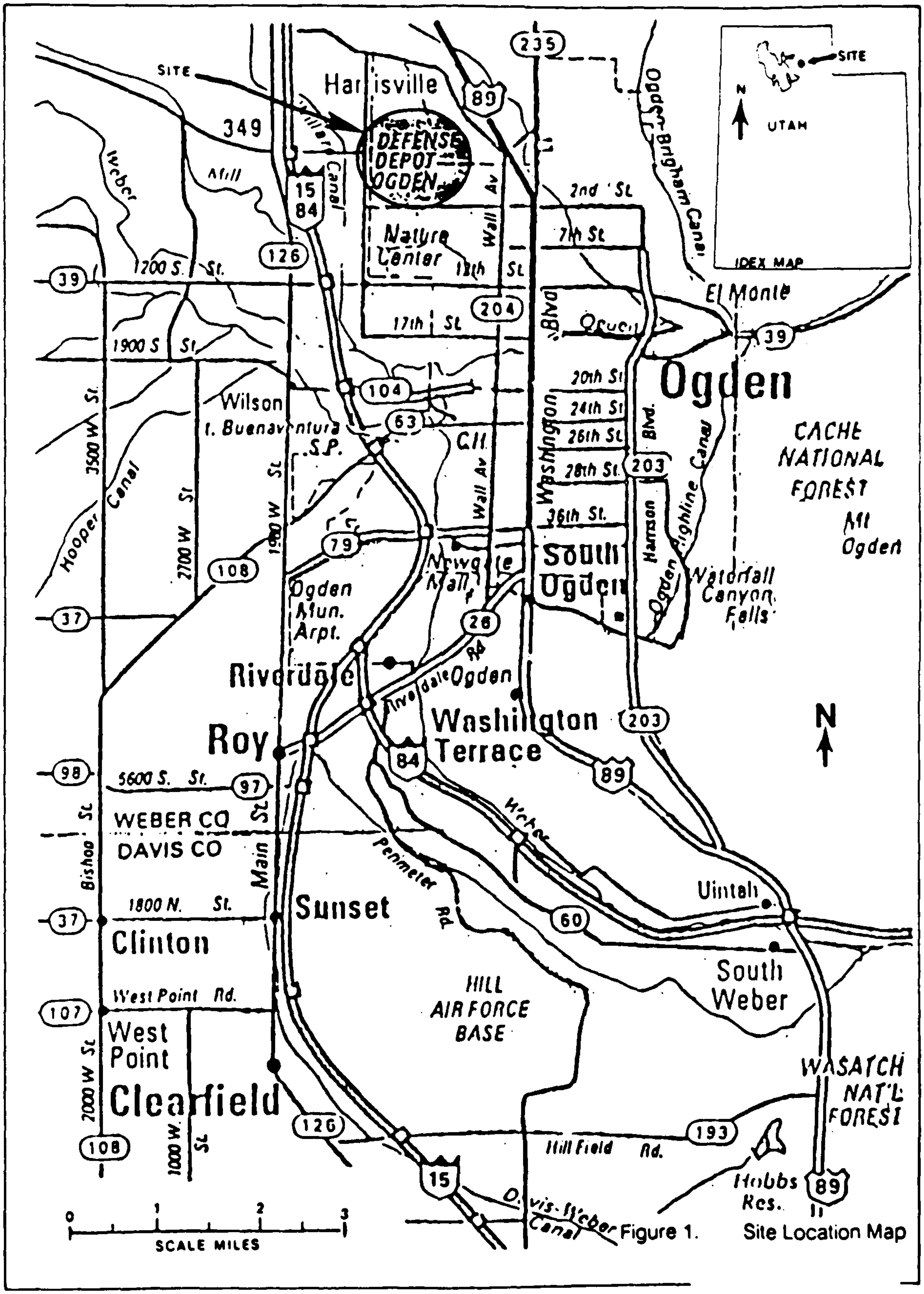


Figure 1. Site Location Map

The actual survey site measures roughly 460 feet by 380 feet and covers an area of 174,800 square feet (Figure 2). It is flat, grass covered and is located immediately northwest of a series of earthen storage igloos. Burial Site 3A is located approximately in the center of the survey site. Burial Site 3A is a polygon-shaped area of approximately 64,000 square feet and is bounded by a chain link fence.

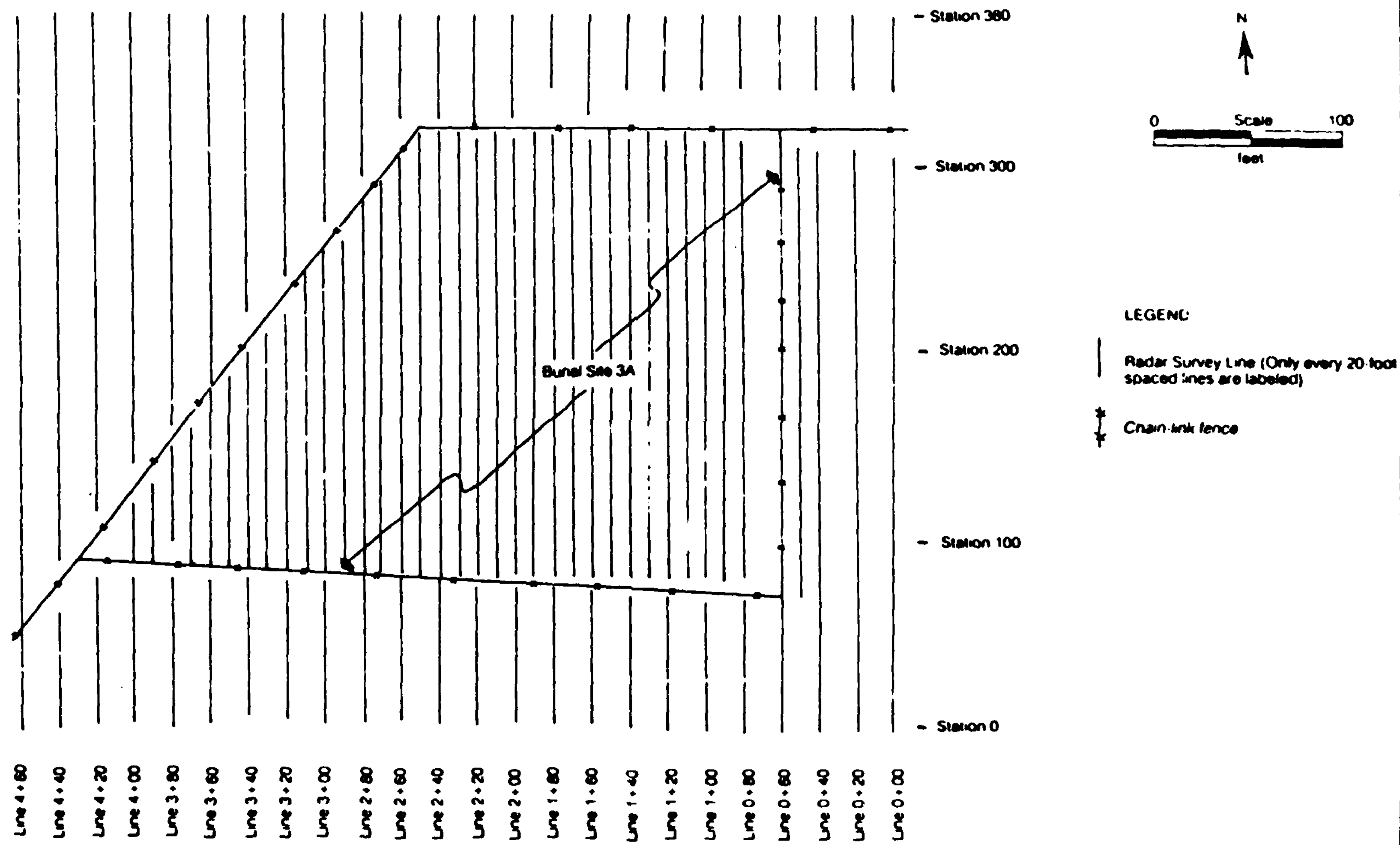


Figure 2 Survey Line Map

2. PURPOSE AND SCOPE

Technos, Inc. was contracted by US Army Waterways Experiment Station, Vicksburg, Mississippi to carry-out a ground penetrating radar (radar) survey of Burial Site 3A to aid in locating any burial trenches or discrete buried objects.

From November 29, 1989 through December 1, 1989, Technos, Inc. carried-out a radar survey at and in the area surrounding Burial Site 3A. The Scope of Work included:

- running the radar survey over a 380 by 460 feet site survey grid established by WES personnel;
- analyze and interpret the radar data with regards to the location of possible burial trenches and discrete buried objects; and
- submit a report describing the field procedures, analysis and findings.

3. APPROACH AND PROCEDURES

Prior to running the radar survey WES representatives Don Yule and Mike Sharp established a site survey grid with PVC pin-flags on 20-foot centers. Messers Yule and Sharp observed the radar survey, furnished Technos with a field sketch of the survey grid and carried-out an electromagnetic and a magnetometer survey concurrent with the radar survey.

3.1. GROUND PENETRATING RADAR

A GSSI Model 4800 radar system with an 80 MHz antenna was used for the radar survey. Ground penetrating radar uses high frequency electromagnetic waves from less than 100 MHz to 1000 MHz to acquire subsurface information. Energy is radiated downward into the ground from a transmitter and is reflected by natural or man made subsurface features back to a receiving antenna. The reflected signals are recorded and produce a continuous cross-sectional "picture" profile of shallow subsurface conditions.

Reflections of the radar wave occur whenever there is a contrast in dielectric constant or electrical conductivity between two materials. Contrasts in conductivity and in dielectric properties are associated with natural hydrogeologic conditions such as bedding, cementation, moisture, clay content, voids, and fractures. If sufficient contrast in electric properties exists, these conditions will show up in the radar profile. Radar reflections also occur at the contact between soil and man-made structures such as a buried steel pipe.

The vertical scale of the radar profile is in units of two-way travel time (the time it takes for an electromagnetic wave to travel down to a reflector and back to the surface). Two-way travel time is reported in nanoseconds (1 nanosecond = 10^{-9} seconds). The time scale is converted to depth by assuming a travel time for electromagnetic waves in the subsurface material.

Depth of penetration of the radar wave is highly site-specific. Penetration is limited by attenuation and scattering when subsurface materials are highly conductive and/or fine grained. Generally, radar penetration is better in dry, coarse grained, sandy soils or in massive rock; poorer results are obtained in wet, fine grained clayey (conductive) soils.

3.2. FIELD PROCEDURES

Prior to beginning the survey, a test was carried-out to evaluate the performance of a 80 MHz and a 300 MHz antenna under existing soil conditions. The test was carried-out in the southeast corner of the survey site.

Site soil conditions, at least at the surface, are moist to wet silts and clays, and it is assumed that these conditions are generally uniform with depth. These soils were "frozen" during the early morning hours and became soft and piable as the day progressed. Localized areas of disturbed soils due to either vehicular traffic and/or trench excavations were apparent in at the site 3A at the time of the radar survey.

Depth calculations were made using an estimated velocity of 1 foot per 10 nanoseconds (two-way travel time) and were assumed to be linear with depth. This time to depth conversion showed that the 300 MHz antenna could penetrate

only about 2.0 feet of soil as opposed to about 4.5 feet of soil with the 80 MHz antenna. Therefore, the 80 MHz antenna was selected as the survey antenna since burial trenches are known to be as much as 6.5 feet (2 meters) deep.

Radar survey lines were run north to south along each row of pin-flags established by WES personnel. Within the fenced area, radar survey lines were also run north to south between each row of pin-flags. Survey lines were spaced 20 feet apart outside Burial Site 3A and 10 feet apart inside Burial Site 3A. A 10-foot offset was applied to part of one survey line that coincided with a fence line (Line 0+60). The location of all radar survey lines are shown in Figure 2.

For this project, the radar range was set to 60 and 90 nanoseconds. The range setting was changed to 90 nanoseconds midway through the first day of survey because "deeper" reflectors became more apparent and it was decided to include as much of the "deeper" reflectors within the record as possible. The records were annotated in the field with the appropriate vertical time scale.

The radar antenna was hand-towed along each survey line at speeds ranging from 1 to 2 miles per hour. Each time the antenna passed a pin-flag location, the radar record was marked.

The military periodically treats a 10 to 20-foot swath along the perimeter with a herbicide to control the growth of grass and weeds. The treated area is denude of foliage, becomes wet and extremely slippery during the day, and could not be physically surveyed with radar. These areas without radar coverage are located primarily along the northern and northwestern perimeter of Burial Site 3A (Figure 2).

4. RESULTS AND INTERPRETATION

The results and interpretation presented in this section are based upon a total of approximately 11,835 linear feet of RADAR data along 41 survey lines. Overall, the quality of the data is considered good for existing site conditions.

Two (2) types of anomalies were identified in the data:

- o hyperbolic-shaped radar targets; and
- o dipping radar reflectors (not caused by fence interference).

The following is a detail discussion of each of these key features. Depths are calculated based upon an estimated velocity of 1 foot per 10 nanoseconds (two-way travel) linear with depth. This estimated velocity is reasonable as a first-order approximation for site soil conditions which are mainly moist to wet silts and clays.

4.1. HYPERBOLIC RADAR TARGETS

A total of 33 hyperbolic-shaped radar targets were identified. These targets are listed in Table 1 and their locations are shown in Figure 3.

Hyperbolic-shaped targets are categorized into 2 groups based primarily upon the size of the target: those that are small and isolated, and those that are wide (15 to 20 feet wide).

Small targets are interpreted as possibly representing man-made objects that may include ordnance, cannisters, drums, or debris related to military operations. Small localized targets probably do not represent cobbles or boulders since neither cobbles or boulders are present at the surface. Some of the targets are

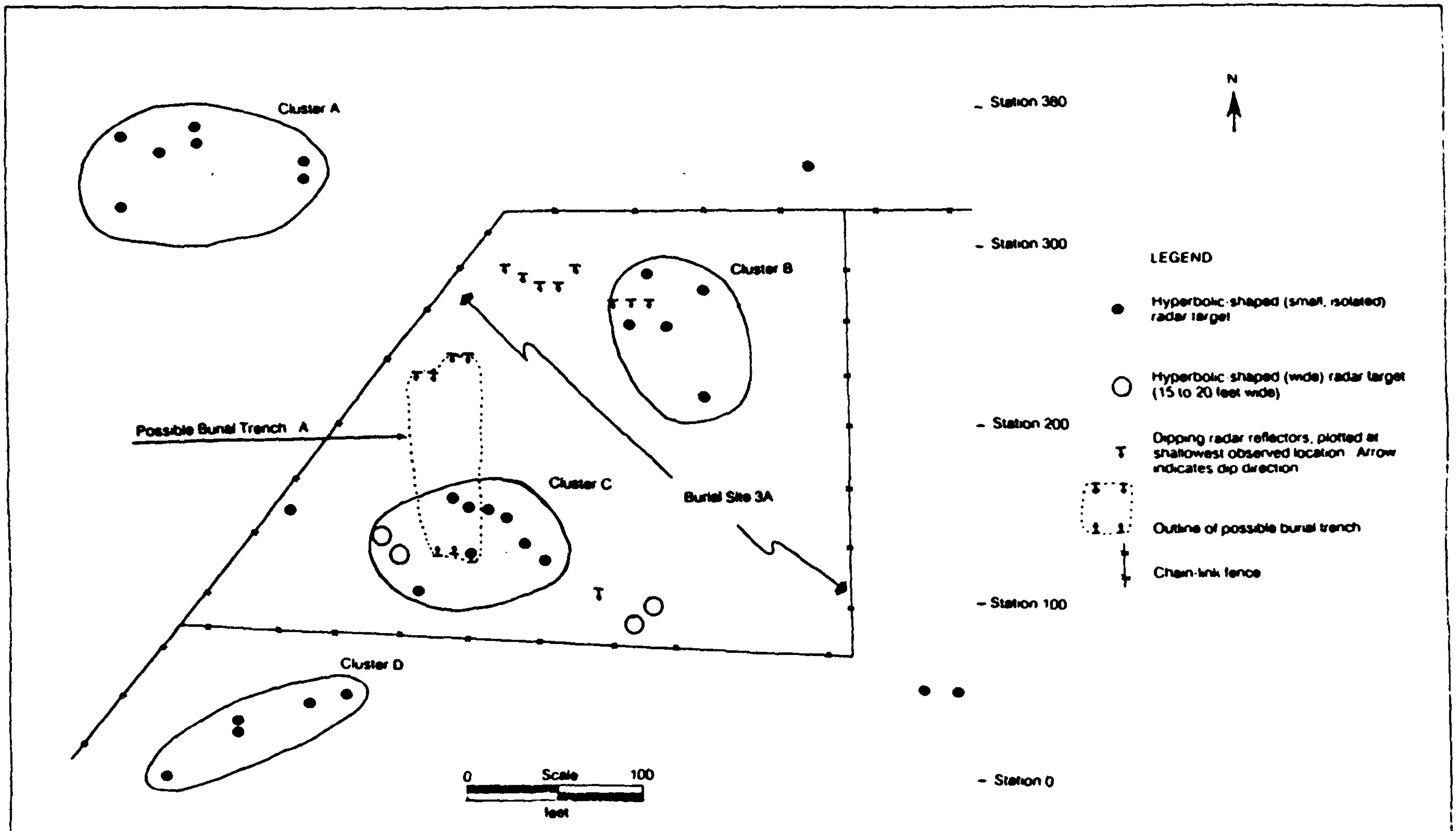


Figure 3 Map of Radar Anomalies

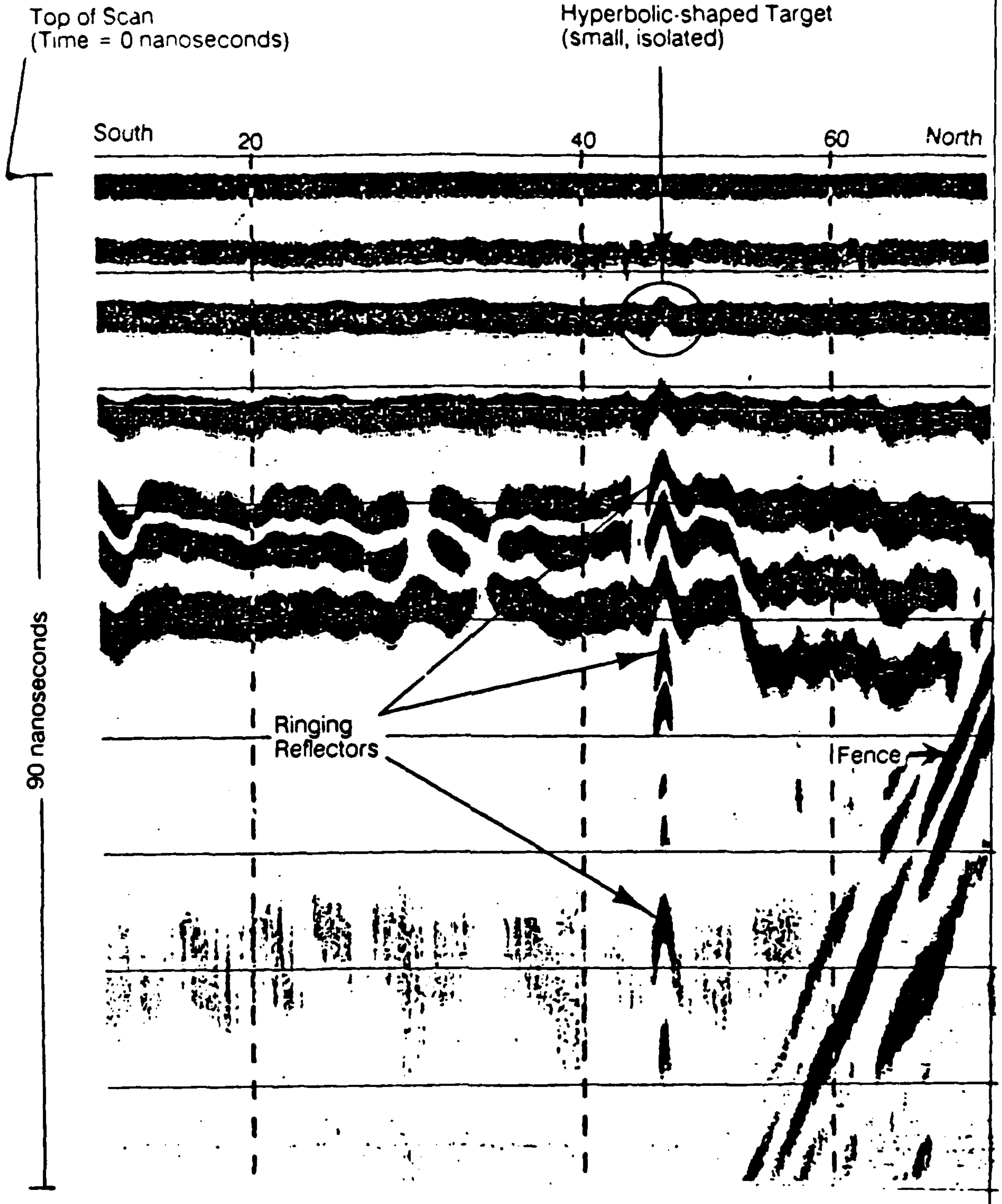
associated with "ringing" which is usually an indication of a shallow metal target. Small targets are buried at depths ranging from about 1.0 to 7.5 feet. The average depth of burial is roughly 3.0 feet. Figure 4 is a representative radar record of a small localized hyperbolic-shaped radar target with "ringing" reflectors.

Wide hyperbolic targets are typically 15 to 20 feet wide. It is uncertain whether the wide targets identified in this survey are related to localized changes in geologic conditions or an indication of man-made buried material. Wide hyperbolic targets occur at depths of 4.0 to 5.0 feet. Figure 5 is a representative radar record of a wide hyperbolic-shaped radar target.

Of the 33 hyperbolic-shaped radar targets identified, 29 are small and 4 are wide (Table 1). Fourteen (14) small localized targets and all 4 of the wide targets are located within Burial Site 3A (Figure 3). Twenty five (25) small targets and 2 of the 4 wide targets form four (4) obvious clusters each of which contains 5 or more targets. These clusters are shown in Figure 3 as clusters A, B, C and D. Clusters B and C are located within the Burial Site 3A.

4.2. DIPPING RADAR REFLECTORS

Sixteen (16) dipping radar reflectors which may indicate the edge of a trench, are apparent in the data. The location of dipping radar reflectors are listed in Table 2. The reflectors are generally discontinuous with depth and their amplitudes sometimes decrease with depth. The trench bottoms are not seen. Most of the dipping reflectors are fairly prominent. Figure 6 is a typical record of dipping radar reflectors that are not caused by fence interference.

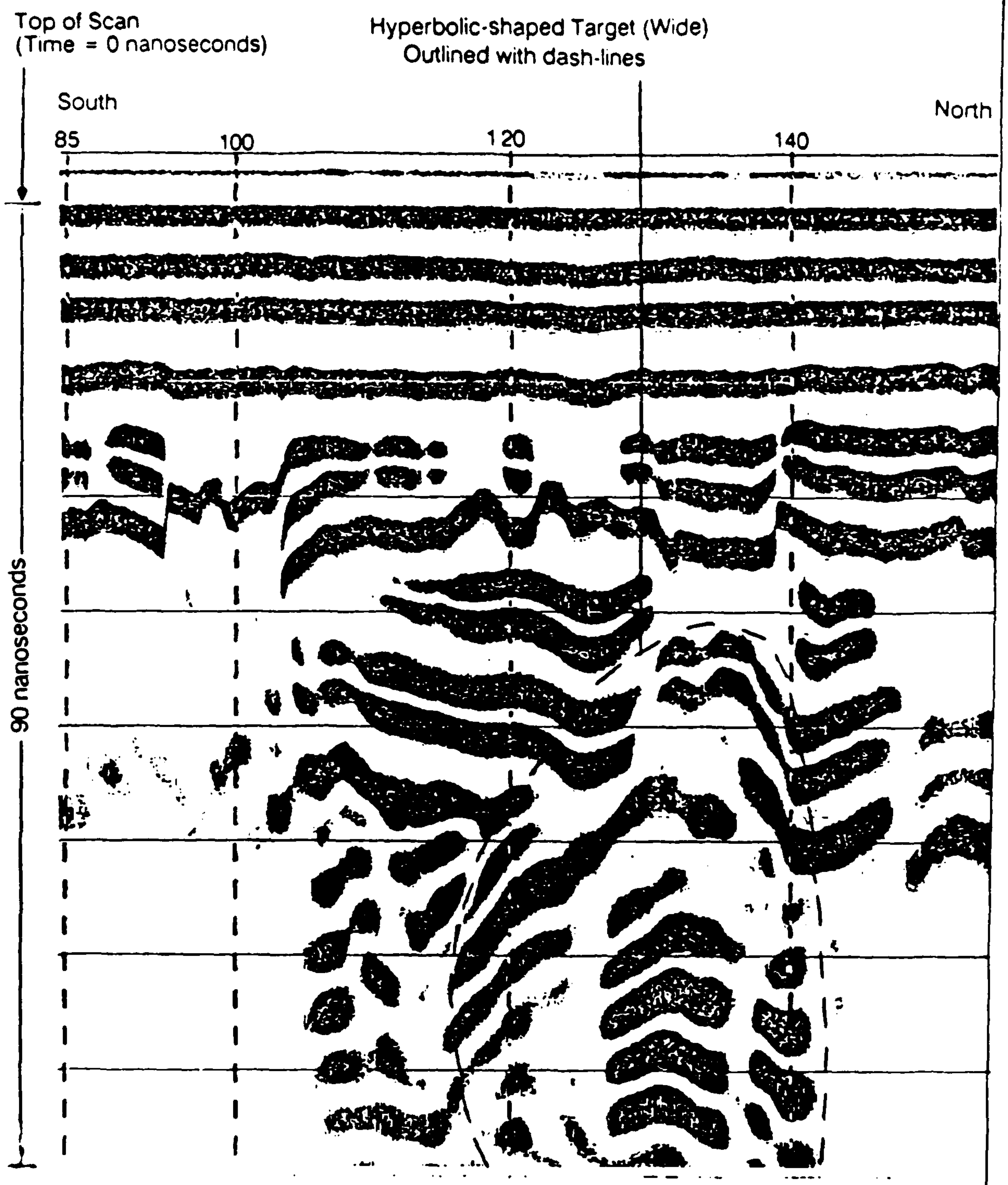


Estimated Total Depth =
9 feet (1 foot/10 nanoseconds)

Horizontal Scale indicated by station marks

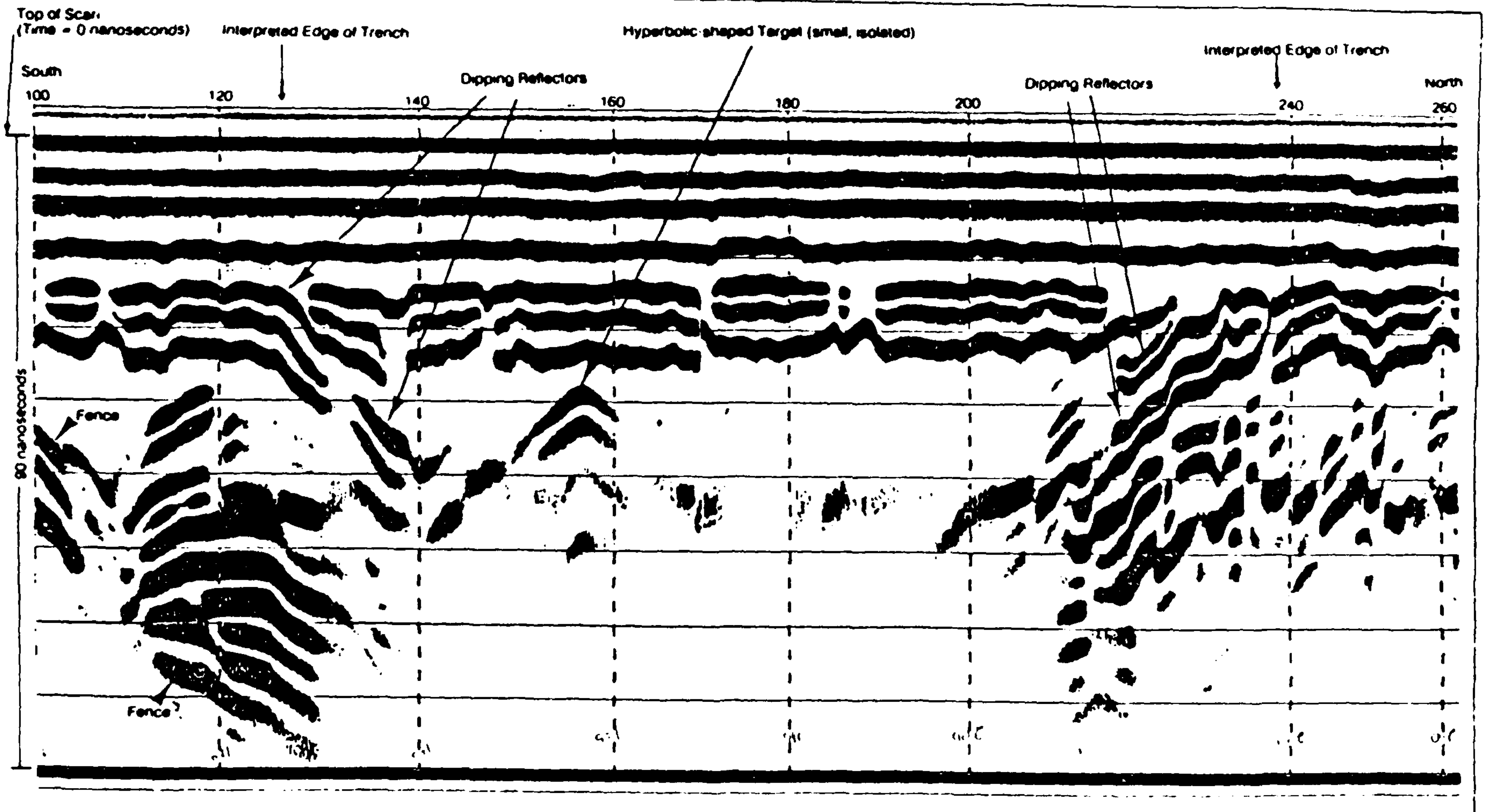
Line 3+60, Stations 20 to 60

Figure 4. Representative Radar Record of Small Hyperbolic Target



Estimated Total Depth =
9 feet (1 foot/10 nanoseconds)
Horizontal Scale indicated by station marks
Line 3 + 10, Stations 85 to 140

Figure 5. Representative Radar Record of Wide Hyperbolic Target



Estimated Total Depth =
9 feet (using 1 foot/10 nanoseconds)
Horizontal Scale indicated by station marks
Line 2+80, Stations 100 to 260

Figure 6 Representative Radar Record of Dipping Reflectors

An apparent dipping reflector is also caused by the radar antenna moving toward or away from the chain-link fence around the site. However, dipping reflectors clearly not associated with fence interference were identified at a total of 16 locations.

Dipping radar reflectors interpreted as trench edges are all located within Burial Site 3A (Figure 3). The outline of a possible burial trench is defined at 7 locations were dipping radar reflectors have been identified. This possible burial trench is shown in Figure 3 as Trench A. It measures about 100 to 115 feet long and about 20 to 30 feet wide; and is located in the western portion of Burial Site 3A.

4.3. FACTORS AFFECTING RADAR RECORDS

Radar records were affected by a number of factors. Interference from the chain-link fences was seen on most of the survey lines and it is manifested on radar records as a pattern of dipping reflectors within roughly 20 to 30 feet of the chain-link fences.

- o Some degree of electronic noise was experienced during the beginning of the survey. Those records which had appreciable noise, such that the noise affected the quality of the records, were re-run. About only 1% of the data shows some degree of noise, however, the noise is considered minimal. Records that have a minimal amount of noise are located along Line 0+60, Stations 80 to 90; Line 0+80, Stations 30 to 40 and 60 to 75; Line 1+100, Stations 0 to 60; and Line 1+20, Stations 0 to 75.

- In a few cases, a constant survey speed could not be maintained because of wet, slippery soil conditions. A stop and go "jerky" motion was experienced under these conditions and resulted in disturbed reflectors along Line 1+70, Stations 280 to 320 and Line 1+80, Stations 280 to 320.

5. SUMMARY AND CONCLUSIONS

A total of 33 hyperbolic-shaped radar targets were identified, 29 of which are small and isolated, and 4 are about 15 to 20 feet wide. The small localized hyperbolic reflectors probably represent man-made objects such as ordnance, cannisters, drums or other debris related to disposal activities at DDOU. The wide targets may represent localized changes in geologic conditions or larger buried material. The small 33 localized targets are buried at depths ranging from 1.0 to 7.5 feet below the surface. The 4 wide targets are buried about 4.0 to 5.0 feet below the surface.

- Fourteen (14) small isolated targets and all 4 of the wide targets are located within Burial Site 3A;
- Twenty five (25) small, isolated targets and 2 of the 4 wide targets form four (4) obvious clusters each of which contains 5 or more targets;
- Two of the 4 clusters (clusters B and C) are located in Buried Site 3A (Figure 3).

- Dipping radar reflectors suggestive of trench edges were identified at 16 locations all of which are within Burial Site 3A;
- Seven of the 16 locations define a possible burial trench that is 100 to 115 feet long and 20 to 30 feet wide (possible Burial Trench A, see Figure 3);
- Three (3) of the small isolated targets in Cluster C are located within possible burial trench A.

TABLE 1
LIST OF HYPERBOLIC-SHAPED RADAR TARGETS

LINE NUMBER	STATION	ESTIMATED DEPTH OF BURIAL (feet)[1]	COMMENTS
Small And Isolated			
0+00	50	5.0	
0+20	50	5.0	
0+80	345	1.0	Slight ringing
1+40	215	2.5	Ringing
1+40	275	1.0	Ringing
1+60	255	3.5	
1+70	285	2.5	Associated with dipping reflectors
1+80	255	4.5	
2+30	125	2.5	Maybe as shallow as 2.0 feet
2+40	135	1.0	Ringing
2+50	150	3.5	Very faint
2+60	155	3.5	Very faint
2+70	130	3.5	
2+70	155	3.5	Very faint
2+80	160	3.5	
3+00	110	7.5	
3+40	50	4.0	Ringing
3+60	45	1.0	Ringing
3+60	340	1.5	Ringing
3+60	350	1.5	
3+70	155	3.5	
4+00	30	3.0	
4+00	35	4.0	
4+20	360	2.5	Slight ringing
4+20	370	3.5	
4+40	5	3.0	
4+40	355	2.0	
4+60	325	1.5	Slight ringing
4+60	365	1.5	Slight ringing
Wide			
1+70	100[2]	4.0	
1+80	90[2]	4.5	
3+10	130[2]	4.0	
3+20	140[2]	5.0	

1 Based upon an assumed velocity of 1 foot/10 nanoseconds. Rounded to nearest 0.5 feet.

2 Approximate center of target. Wide targets are about 15 to 20 feet wide.

TABLE 2
LIST OF DIPPING RADAR REFLECTORS

LINE NUMBER	STATION*	DIP DIRECTION	COMMENTS
1+70	280	South	Prominent
1+80	280	South	Prominent
1+90	280	South	Prominent
2+00	110	South	Prominent
2+10	290	South	Faint
2+20	280	South	Faint
2+30	280	South	Faint
2+40	285	South	Faint
2+50	290	South	Faint
2+70	125	North	Prominent
2+70	240	South	Prominent
2+80	130	North	Prominent
2+80	240	South	Prominent
2+90	130	North	Prominent
2+90	230	South	Prominent
3+00	230	South	Prominent

* Shallowest observed location.